THE UNIVERSITY OF ALBERTA

SOIL SALINITY IN SOUTHWESTERN ALBERTA AS RELATED TO GROUND WATER SEEPAGE

BY

GRAEME MICHAEL GREENLEE, B. Sc.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

APRIL 1966

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "Soil Salinity in Southwestern Alberta as related to Ground Water Seepage" submitted by Graeme Michael Greenlee, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

In the study area, considerable salt seepage has occurred, and high concentrations of salts have been built up in the soil over the years in which the land has been cultivated. Accumulations of salts can frequently be seen on hill slopes and in road cuts. Many saline areas have had to be abandoned, since they have been rendered unproductive by the presence of high concentrations of salts. It is the general consensus of opinion of farmers and of other persons who have worked in the study area that the extent of salinity is increasing.

In general, the parent materials from Vulcan to High River and from Calgary to Gleichen have relatively high salt contents. These salts tend to move laterally in the soil to lower positions in the landscape, possibly through lenses that are somewhat coarser in texture than the underlying soil.

The surficial geology of the Vulcan area is mainly glacial drift in the form of ground moraine, although resorting of much of the surficial material is evident.

The Paskapoo geological formation occurs as the uppermost formation, below surficial deposits, in the study area. This formation consists largely of alternating series of hard sandstones with soft porous sands, shales and sandy shales, providing conditions that seem to be ideal for the movement of saline ground water.

From a study of salinity maps, that were prepared from photographs taken in different years, it appears that the extent of salinity has increased substantially with time.

Soil profiles were sampled at four separate locations on saline

slopes. Deep parent geologic material samples were collected at various locations. Physical and chemical analyses were conducted in order to characterize the soils and parent materials under study and assist in the classification of the soils.

Shallow wells (10 to 15 feet deep) were drilled at three locations, at each of the four soil sampling sites. Sodium fluorescein was placed in the well at the top of each slope, and water samples were collected from all the wells in order to determine whether or not the dye had moved down slope with the ground water. Water table samples were also collected for soluble salt analysis, and water table depths were recorded during April to November of 1965.

Soluble salt analysis of ground water, soil, and parent geologic material samples suggest that bedrock is the main source of the salts. Sodium sulfate appears to be the principle soluble salt accumulated in soil horizons, thus indicating that the major portion of the salts may be transported by regional ground water flow. Higher concentrations of magnesium sulfate than sodium sulfate in soil and ground water samples at one of the locations indicate that till may also be a source of the salts, and that local or intermediate ground water flow may occur in some areas. Variations observed in the dye movement also indicate the presence of local flow systems.

Variations in water table levels down slope, at the various sites, are somewhat erratic, and may be the result of local topographical variations. However, fluctuations in water table levels with the season of the year generally occur.

From the soil classification, it appears that extensive resalinization of the soils has occurred. However, Solonetzic morphological features are not evident in any of the soils studied.

ACKNOWLEDGEMENTS

Sincere appreciation is extended to Dr. S. Pawluk, Associate Professor of Soil Science, for his guidance and encouragement in conducting this study, and for his assistance and patience in the preparation and reviewing of the manuscript.

Further thanks are extended to Dr. J. A. Toogood, Professor and Head of the Department of Soil Science, for reviewing the manuscript.

Appreciation is also extended to the following: C. J. Roth, former District Agriculturist at Vulcan, for his cooperation during the course of the field work; W. E. Bowser, Head of the Alberta Soil Survey, Research Branch, Canada Department of Agriculture, for reviewing the manuscript and giving helpful suggestions; T. W. Peters, Soil Surveyor, Research Branch, Canada Department of Agriculture, for assistance in sampling the soils and drawing the salinity maps, and to other members of the Soil Survey staff who at frequent intervals rendered valuable assistance to the author; E. G. Le Breton, Ground Water Geologist, Ground Water Division, Research Council of Alberta, for his valuable comments and observations regarding the ground water aspects of the study; Dr. L. A. Bayrock, Pleistocene Geologist, Research Council of Alberta, for assistance rendered in identifying deep drill samples in the field; the members of the examining committee; Mrs. B. Bonnell, for typing the rough draft of the thesis; and Miss Phoebe Hines, for typing the manuscript.

Special thanks are extended to the following: R. A. Milne, Research Officer, Research Branch, Canada Department of Agriculture, for the use of the Sterling Drill, which belongs to the Lethbridge Research Station, and for his assistance and cooperation during the field work and in recording

water table levels in the wells used in the study; L.D.M. Sadler, Head of the Colonization Branch, S.M.R.D., Alberta Department of Agriculture, for the use of the deep drill, which belongs to the Colonization Branch, and to other members of his staff who operated the deep drill during sampling; Dr. K. W. Geiger, Ground Water Geologist, Ground Water Division, Research Council of Alberta, for providing two of the maps included in the thesis, and for his valuable aid in interpreting the results with regard to the ground water aspect of the study; Canada Department of Agriculture for financial assistance, in that the author was employed on full salary during the last 2 years of the study; and to the Cartographic Section, Soil Research Institute, Central Experimental Farm, Ottawa, for printing the salinity maps included in the thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure	Page

LIST OF PLATES

I. INTRODUCTION

Soils are formed by the weathering of rock material, and salts come originally from this decomposed rock (Wyatt _et al._, 1942). These salts, when set free by the decomposition of the rocks tend to accumulate wherever rainfall is not sufficient to carry them away in drainage water or where downward drainage is impeded by consolidated or impermeable material.

Saline lands usually occur in areas where the annual rainfall is less than 20 inches (Wyatt _et al._, 1942). It has been estimated that approximately one-third of the earth's land surface is arid or semi-arid. Distributed here and there over dry regions of every continent, saline and alkali soils occur in areas varying in size from a few square yards to thousands of acres (Kelley, 1951).

Salts generally occur in the least elevated parts of a given drainage basin, in valleys and depressions that receive drainage from surrounding soils and from which there is no drainage outlet (Wyatt _et al._, 1942; Kelley, 1951). However, salts also occur in level land that is not very well drained, even though the land may be slightly elevated (Wyatt _et al._, 1942).

The major salt movement in soils takes place through the medium of water (Qayyum, 1962). Soluble salts accumulate wherever drainage water evaporates, where evaporation exceeds precipitation or has done so at some previous time. This is possible only where precipitation falling on one area drains to another, where it evaporates. Drainage may be surface or subsurface, but is most commonly the latter (Kelley, 1951).

Saline and alkali soils are most commonly found where ground water

is or has been sufficiently near the surface to permit the capillary rise of water, together with dissolved salts, into the topsoil where evaporation can take place (Kelley, 1951; Qayyam, 1962). When the water table rises to within 5 or 6 feet of the soil surface ground water moves upward into the root zone and to the soil surface (Handbook 60).

Ground water of dry regions is usually considerably more saline than ground water of humid regions. In dry regions, as ground water rises, soluble salts of the porous media dissolve, thus increasing the ground water salt concentrations. In humid climates, natural precipitation is usually sufficient to leach out the soluble salts approximately as fast as they are released. They then pass downward and out with the natural drainage (Kelley, 1951).

A saline horizon designated as "sa" by the National Soil Survey Committee of Canada in 1963, is a horizon with secondary enrichment of salts more soluble than carbonates where the concentration of salts exceeds that present in the unenriched parent material. A "saline soil" is defined as having saline A, B, and C horizons.

Direct sources of salts under conditions of dry land salt accumulation may be salt-carrying marine sedimentary rocks or continental salt-carrying deposition (Vilenskii, 1957). Also, shales of dry regions are prolific sources of soluble salts (Kelley, 1951). However, salts which accumulate in a given place have for the most part not been formed at that place. They have been transported there, largely by means of water (Kelley, 1951). Important sources of salts in glaciated regions may be evaporite beds in various geological formations. Salts may have been incorporated in glacial drift as ice was overriding these beds, and so transported by ice.

The kind of geological formation from which ground water has come, or through which it has passed, largely determines what kind of salts will be deposited in the soil. Saline and alkali soils which have originated from shales and sandstones are likely to be high in chlorides, and sulfates of sodium, calcium and magnesium (Kelley, 1951). Saline soils which have originated from till are likely to be high in calcium and magnesium carbonates. The rate of accumulation of soluble salts depends upon the evaporation rate, salinity of the soil solution, and the amount and seasonal distribution of precipitation (Kelley, 1951).

Subsoils may contain soluble salts to considerable depths, but saline subsoils are not always continuous over a wide area. Spottiness similar to that of the surface may characterize the subsoil horizons (Kelley, 1951).

In general, the parent materials from Vulcan to High River and from Calgary to Gleichen have relatively high salt contents. These salts tend to move laterally in the soil to lower positions in the landscape, possibly through lenses that are somewhat coarser in texture than the underlying soil. Also, accumulations of salts can frequently be seen on hill slopes and in road cuts (Wyatt et al., 1942).

The Paskapoo geological Formation occurs as the uppermost formation below surficial deposits in the study area. This formation consists largely of alternating series of hard sandstones with soft porous sands, shales and sandy shales (Williams and Dyer, 1930), conditions that seem to be ideal for the movement of saline ground water.

In the study area (fig. 1a), considerable salt seepage has occurred and high concentrations of salts have been built up in the soil over the years in which the land has been cultivated. Many saline areas have had

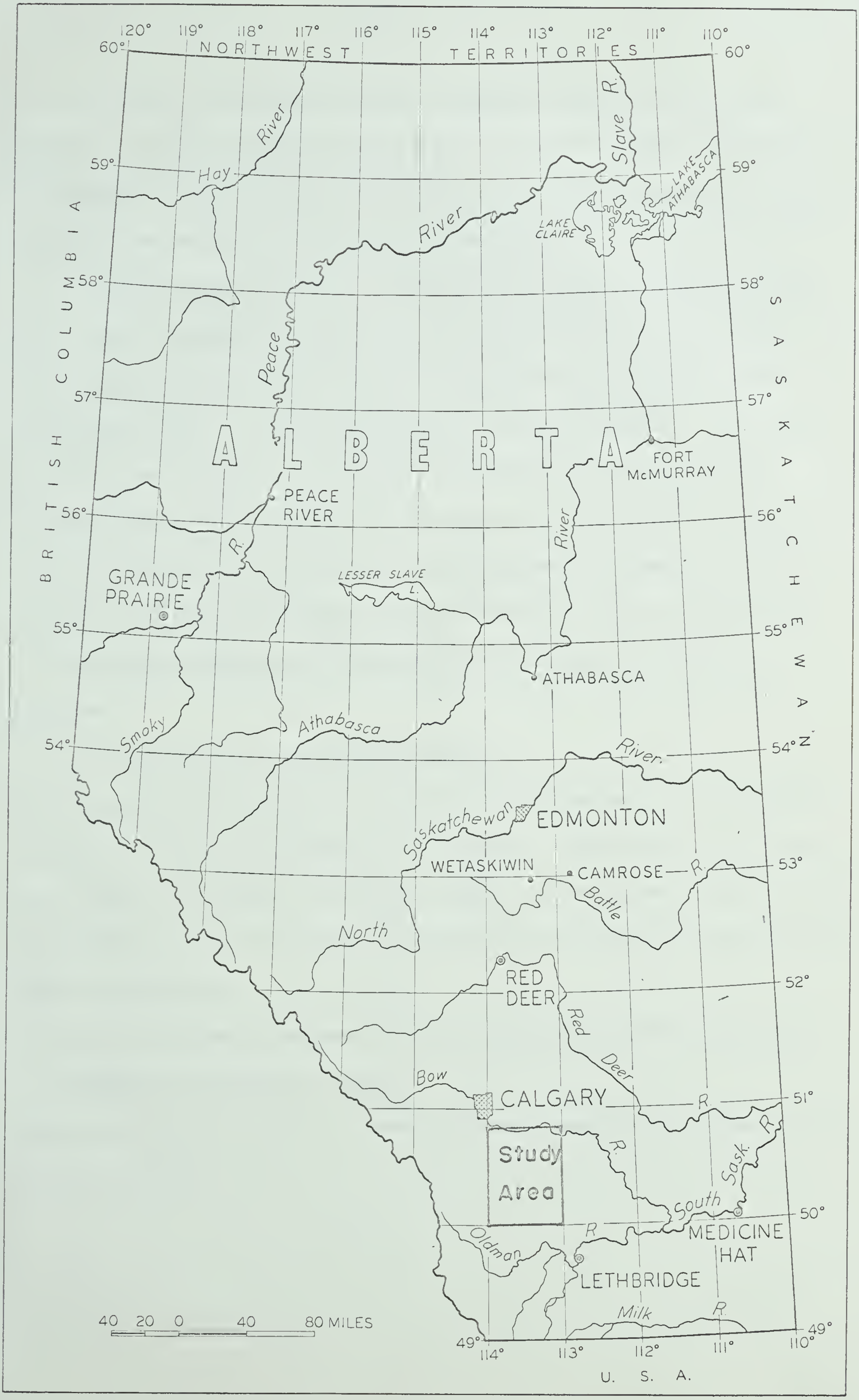


Figure 1a. Map showing Location of Study Area

to be abandoned, since they have been rendered unproductive by the presence of high concentrations of salts. It is the general consensus of opinion of farmers and of other persons who have worked in the study area that the extent of salinity is increasing.

Resalinization of soils on slopes where salts, especially sodium salts, have accumulated over the years may have affected the genesis of these soils. It is thought that salt concentrations may have become sufficiently high to initiate Solonetzic soil development. Solonetzic soils may have formed in areas where fluctuating water tables have provided sufficient drainage to allow excess soluble salts to be leached out of the profiles, thus leaving sodium-saturated exchange complexes in the upper horizons. Sufficient sodium saturation can cause dispersion of the exchange complex and initiate the development of Solonetzic B horizons.

The objectives of this study were to:

(1) Delineate saline areas from aerial photographs and try to determine the rate at which soil salinity is increasing. Photographs of the same areas taken in different years were studied and an attempt made to determine whether or not the extent of salinity has increased during intervals between photography.

(2) Study ground water movement and try to determine where the salts are coming from and how they move.

(3) Conduct a study of the influence of resalinization upon genetic soil characteristics.

II. LITERATURE REVIEW

Ground Water and Ground Water Movement

Water-bearing formations of the earth's crust act as conduits for the transmission of and as reservoirs for the storage of water (Todd, 1959). Ground water designates all interstitial water below the water table in the zone of saturation (Tolman, 1937). In the absence of overlying impermeable strata, such as clay beds, the upper surface of the zone of saturation is the water table or the "phreatic water surface" (Todd, 1959). Above this is the zone of aeration, which extends to the ground surface (Tolman, 1937). Interstices in the zone of aeration are occupied partially by water and partially by air (Todd, 1959). The suspended or "vadose" water occurs here.

Todd (1959) subdivided the zone of aeration into three parts. They are:

(1) The "soil water zone," where water exists below the saturation point except temporarily when excess water reaches the ground surface from rainfall or irrigation. This zone extends from the ground surface down through the major root zone, and its thickness varies with the soil type and vegetation.

(2) The "intermediate zone" extends from the lower boundary of the soil water zone to the upper boundary of the capillary zone. This zone may vary in thickness from zero to several hundred feet. Non-moving or pellicular water in this zone is held in place by capillary and hygroscopic forces, with excess water being gravitational, and moving downward under the influence of gravity.

(3) The "capillary zone" extends from the water table up to the limit of capillary rise of water. The capillary zone may vary from a fraction

of an inch to ten feet in thickness, depending upon the sizes of the interstices and the texture of the material immediately above the water table (Tolman, 1937).

Ground water occurs in aquifers, an "aquifer" being defined by Todd (1959) as "a rock formation or material which will yield significant quantities of water." The types of aquifers listed by Todd are as follows:

(1) "Unconsolidated rocks" make up ninety percent of all developed aquifers. These types of aquifers occur under:

(a) Water courses. Alluvium that occupies and underlies stream channels and is in adjacent flood plains contains large quantities of water as infiltration from the streams.

(b) Abandoned or buried valleys. These are no longer occupied by the streams that cut them. They may resemble water courses in permeability and in the quantity of ground water storage, however, their recharge capabilities for perennial yield are usually less.

(c) Plains. These may be underlain by gravel and sand beds which are important aquifers in some places. Ground water reservoirs in these areas are recharged chiefly by downward percolation of water from precipitation and from occasional streams.

(d) Intermontane valleys. These are underlain by tremendous volumes of rock materials. Sand and gravel beds of these aquifers produce large quantities of water, most of which is replenished by seepage from streams into alluvial fans at mouths of mountain canyons.

(2) "Sandstone and conglomerate" are cemented forms of sand and gravel

whose porosity and yield have been reduced by the cementing. The best sandstone aquifers are those which have been only partially cemented.

(3) "Limestones" vary greatly in density, porosity and permeability.

(4) "Volcanic rocks" may form permeable aquifers.

(5) "Crystalline and metamorphic rocks" are relatively impermeable and are poor aquifers.

(6) "Clay and coarse materials mixed with clay" are generally porous but are relatively impermeable.

Two main types of aquifers occur in Alberta (Meneley, 1963). They are:

(1) Bedrock aquifers. These include fine-grained sandstone, sandy shale, shale and coal strata. They range from unconsolidated to completely indurated strata.

(2) Surficial aquifers. These include alluvial sand and gravel deposits, and outwash and stream-trench deposits underlying or intercalated with till.

"Seepage" is "the movement of water into or out of the ground" (Tolman, 1937). Movement of water into the ground from the surface down is called "influent seepage," and discharge of ground water to the surface is called "effluent seepage."

Most ground water originates as surface water (Todd, 1959). The two principal sources of natural recharge are precipitation, and influent seepage from streams, lakes and reservoirs (Tolman, 1937; Todd, 1959). Also, influent seepage from irrigation ditches and heavy surface irrigation may replenish ground water supplies (Tolman, 1937). In general, rainfall contributions increase in importance as climate becomes more humid, and influent seepage from streams increases in relative importance to rainfall

increments as climate becomes more arid.

Discharge of ground water occurs when water emerges from underground (Todd, 1959). Ground water near the surface may return directly to the atmosphere by evaporation from within the soil and by transpiration from vegetation. However, most natural discharge occurs as flow into surface water bodies, such as streams, lakes and oceans. The outcrop of the water table is marked by the uppermost appearance of effluent seepage, the upper limits of permanently-moistened areas such as swamps, and the changes in vegetation from non-phreatophytes to phreatophytes (Tolman, 1937).

A "spring" is "a concentrated discharge of ground water appearing at the ground surface as a current of flowing water" (Todd, 1959). To be distinguished from springs are "seepage areas," which indicate slower movements of ground water to the ground surface. Water in seepage areas may pond and evaporate or flow, depending upon the magnitude of seepage, the climate, and the topography.

A "perched water table" is "the upper limit of a body of saturated material supported by an impervious stratum below pervious deposits within the zone of aeration" (Tolman, 1937). Underlying the saturated pervious material and separating it from the main water table are partially-saturated formations of the zone of aeration.

"Free ground water" is "water in interconnected interstices down to the first impervious barrier." "Confined ground water" is "ground water overlain by material sufficiently impervious to cut off free hydraulic connection with all overlying ground water except at the upper edge of the confining stratum where the confined water connects with free ground water" (Tolman, 1937).

There are four distinct types of subsurface water movement, namely: seepage, capillary rise, ground water turbulent flow, and percolation (Tolman, 1937).

"Seepage" from the ground surface to the water table is firstly "a slow diffuse movement by which the surfaces of all openings are wetted," and secondly "a downward movement of gravity water on the films coating the openings."

"Capillary movement" of water occurs in the capillary fringe immediately above the water table.

"Ground water turbulent flow" may occur in openings of large size, such as fractures or turbulent openings, and possibly in interstices in very coarse sedimentary and alluvial material under high hydraulic gradients sufficient to develop turbulent movement. However, natural ground water gradients are usually too small to develop turbulent flow except in large conduits above or at the water table and in conduits below the water table where free escape permits rapid movement or in the vicinity of intake of a pumping well.

"Percolation" is "slow movement of water in interconnected pores of saturated granular material under hydraulic gradients commonly developed underground."

Fluctuations of ground water levels result mainly from:

(1) secular and seasonal variations.

(2) fluctuations caused by evapotranspiration (Todd, 1959).

"Secular" variations of ground water levels are "those extending over periods of several years or more." Alternating series of wet and dry years, in which rainfall is above or below the mean, will produce long-period fluctuations of ground water levels. Rainfall is not an

accurate indicator of ground water level changes; recharge is the governing factor. The rate of recharge depends upon rainfall intensity and distribution, and the amount of surface runoff. Many ground water levels show seasonal patterns of fluctuation. They may result from influences such as recharge from rainfall and irrigation, and discharge from pumping, which follow well-defined seasonal cycles.

Unconfined aquifers with water tables near the ground surface frequently exhibit diurnal fluctuations which can be the result of evaporation and/or transpiration. Both of these processes cause discharge of ground water into the atmosphere and have nearly the same diurnal variation because of their high correlation with temperature. Evaporation from ground water is negligible unless the water table is near the ground surface. Rates of evaporation depend upon the position of the capillary zone relative to the ground surface. Transpiration discharge does not occur in non-vegetated areas such as plowed or summer-fallowed fields, nor in areas where the water table is far below the ground surface.

Todd (1959) defines a "ground water basin" as "a physiographic unit containing one large aquifer or several connected and interrelated aquifers."

Hubbert (1940), as discussed by Meneley (1963), describes the mechanics of gravitational flow in a homogeneous isotropic medium. He states that "below the free-water surface, water moves under the influence of gravity from a region of higher fluid potential toward regions of lower fluid potentials." The fluid potential is the algebraic sum of the hydrostatic pressure potential and the gravity potential. It may be determined from measured static water levels in nonpumping wells.

Flow will occur from a region with a lower hydrostatic pressure to a region with a higher hydrostatic pressure only if the latter region has a lower fluid potential. In Alberta, maximum fluid potentials occur under topographic highs (Jones, 1959; Farvolden, 1961b) as discussed by Meneley (1963). It follows that ground water will flow away from topographic highs toward topographic lows. If the flow system is in dynamic equilibrium, the water must be continuously added in upland areas to replace water that is naturally discharged in lowland areas. Because the only available source of water in an upland area is precipitation, ground water flow in Alberta is dependent upon precipitation for its replenishment.

Ground water moves downward in a recharge area, and the fluid potential should decrease with increasing depth. Ground water moves upward in a discharge area, and the fluid potential should increase with increasing depth (Meneley, 1963).

According to Toth (1963), three distinctly different types of flow systems can occupy a basin; namely local, intermediate, and regional systems.

A "local" system of ground water flow has its recharge area at a topographic high and its discharge area at a topographic low adjacent to the high.

The major characteristic of an "intermediate" system of ground water flow is that its recharge and discharge areas do not occupy the highest and lowest elevated places respectively in the basin, rather, more than one topographic high and low may be located between them.

A system of ground water flow is considered to be "regional" if its recharge area occupies the water divide and its discharge area is at the bottom of the basin. Whereas theoretically the boundaries between

different flow systems are very well-defined, they do not signify abrupt changes of any of the physical properties of the flow. Relatively rapid changes in the chemical composition of the water across the boundaries could be expected however, because of the different locations of recharge and the different lengths of flow paths of the different systems.

The major features of ground water flow and flow systems as described by Toth (1963) are as follows:

(1) Under extended flat areas ground water movement is retarded; neither regional nor local systems can develop. Ground water can be discharged only by evaporation, which will possibly result in water-logged areas. If a relation between mineralization of the water and velocity of flow can be assumed, water in these areas will have high concentrations of soluble salts.

(2) If local relief is negligible and if there is a general slope only, a regional system will develop. Theoretically, if the line, located on the surface midway between and parallel to the valley bottom and the water divide, is called the "midline," then the recharge and discharge areas of this system are located between the midline and the divide and the midline and the valley bottom, respectively. Because of decreasing velocities, a gradual increase in dissolved mineral constituents with depth is to be expected.

(3) If the topography has well-defined relief, local systems originate. With increases in relief, the local systems become progressively deeper. Imaginary impermeable boundaries between these local systems may be thought to be located at local highs and lows.

(4) As a result of local flow systems, alternating recharge and discharge areas are found across a valley. This means that the origins of waters

obtained from places located close together may not even be related. Rapid changes in the chemical quality of the water may thus be expected.

(5) Water levels at shallow depths are the most affected by seasonal recharge and discharge. The small intake and outlet areas of the intermediate and regional zones prevent their water levels from fluctuating widely.

(6) Only a small part of the water occupying a basin participates in the hydrologic cycle. With increases in relief, the portion of water entering into the hydrologic cycle, becomes progressively less.

In Alberta, ground water moves by gravitational flow through materials of widely varying physical properties (Meneley, 1963). The plains of Alberta lie on the eastern flank of the Alberta syncline, and the regional dip is westward, rarely exceeding 100 feet per mile and averaging about 20 feet per mile. On the plains, however, the strata may be considered to be horizontally-layered. Some strata have sufficient permeabilities to yield water to wells, and thus may be considered as aquifers according to Meinzer (1923) as outlined by Meneley (1963).

Over most of Alberta, glacial deposits overlie a sequence of sandstone and shale strata of late Cretaceous and Tertiary ages (Meneley, 1963). The thickness and permeability of the glacial deposits vary. Highly permeable materials however, constitute only a small part of their total volume. Similarly, almost all of the sandstone strata are highly lenticular, and are separated by shale and sandy shale. In its gross aspect, the medium through which flow takes place in Alberta is relatively homogeneous, and is composed mainly of materials having very low permeabilities (Meneley, 1963).

The prairie profile of ground water flow in western Canada consists

of a central topographic high, bounded on either side by lower elevations (Meyboom, 1962). Geologically, the profile consists of two layers of different permeability, the upper layer having the lower permeability. Through the profile, there is a steady flow of ground water from the area of recharge to the area of discharge. The ground water flow is essentially downward through the material of low permeability, and lateral and upward through the underlying more permeable material. Meyboom (1962) states that "the prairie profile is seldom complete, because of insufficient lateral extent of the permeable stratum." In that case, only half of the profile can be recognized. This is a topographically high recharge area, and one adjacent discharge area. Probably the "partial prairie profile" is the most common hydrogeological setting for artesian areas. Recharge takes place through the poorly-permeable layer, and natural discharge occurs as upward leakage underneath the adjacent lowland.

Meyboom (1962) states that "most natural ground water discharge on the prairies occurs as evapotranspiration, either directly through the soil or through phreatophytic vegetation."

All ground water contains salts in solution (Todd, 1959). The kinds and concentrations of salts depend upon the environment, movement, and source of the ground waters. On passing from more humified zones to less humified zones, a general salinization of water occurs. Here, a successive transition from bicarbonate waters, through sulfate, to sulfate-chloride and chloride-sulfate waters takes place (Siline-Bektchourine, 1961). High salinities are found in soils and ground waters of arid climates where leaching by rainwater is not effective in diluting the salt solutions (Todd, 1959).

Ordinarily, higher proporations of dissolved constituents are found in ground waters than in surface waters because of the greater exposures to soluble materials in geologic strata (Todd, 1959). Salinization of ground waters is connected with the process of leaching salts out of rock during the time of ground water filtration from the supply region to the places of discharge (Siline-Bektchourine, 1961). In areas such as alluvial streams or artificial recharge areas, where recharge of large volumes of water underground takes place, the quality of the infiltrating surface waters can have a marked effect on the quality of the ground waters (Todd, 1959).

Salts are added to ground water passing through soils as soluble products of soil weathering. Also, solution of soluble materials re-leased by soil erosion from rainfall and flowing water adds salts to ground water (Todd, 1959).

According to Geiger*, the chemical composition of ground water changes with depth. Carbon dioxide, dissolved from the atmosphere by rainfall, increases the solubility of calcium and magnesium carbonates as rainwater infiltrates the soil. In the presence of CO_2 in the soil solution, carbonates are converted to bicarbonates. Consequently, ground water immediately below the water table contains relatively high proportions of calcium and magnesium bicarbonates. At lower depths, gypsum contained in the till is dissolved by the ground water. Through base exchange with clay minerals in the till, sodium bicarbonate and sodium sulfate are formed. Still deeper, where ground water comes into contact with shale strata, sodium sulfate, dissolved from the shale, becomes the predominant salt in the ground water. Where the ground water

*personal communication

is in contact with a rock stratum at some considerable depth, small amounts of sodium chloride may be added to it from below.

In general, salts deposited on the surface by local ground water flow systems will be mainly calcium and magnesium bicarbonates, salts deposited by intermediate flow systems will be mixtures of sulfates and bicarbonates, and salts deposited by regional flow systems will be mainly sodium sulfate. Also, some sodium chloride may be deposited on the surface where very deep regional ground water flow systems come to the surface.

Effect of Vegetation Type on Water Table Levels and Salinity

Changing the type of vegetation in an area may lower or raise the water table level. Land clearing may raise water table levels and increase soil salinity. Rennie (1957) reported that afforestation of heath moors with sitka spruce in northern England in years of dry summer reduced the catchment yield up to three centimeters of water, by its effect on transpiration. Also, Wilde et al. (1953) reported that clear cutting of a forested area in northern Wisconsin removed the intercepting and transpiring canopy and converted a reasonably well-drained podzolized soil into a semi-swamp, by raising the water table.

Bettenay, Blackmore and Hingston (1964) conducted a study of the hydrology and salinity in the Belka Valley of western Australia. In this valley, large areas of the "Ulva" soil association occur around the major drainage divide and on the interfluves between valleys. On the highest points, the soils consist of gravels with an indurated mottled zone, a duricrust, at shallow depths, while down slope there are increasing depths of sands over this impermeable layer. They reported that the natural vegetation on the Ulva series appears capable of absorbing

normal amounts of rainfall, but after clearing, a perched water table is periodically established on the duricrust. This water table may intercept the surface down slope in seepage spots. Bettenay et al. (1964) further stated that "clearing in the Belka Valley led to decreased water usage by plants." With more water reaching the valley floor, more extensive ponding and wetting of the soil profile to greater depths and for longer periods of time were observed. Removal of the vegetation resulted in considerably more water reaching the soil profile. On the sand plain in the valley, this led to greater percolation with subsequent appearances of seepage spots down slope. In valley bottoms, increased accession of surface water led to a more extensive zone of saturation in the soil above the aquifer. Wetter conditions improved the water-transmitting ability of the profile and resulted in more rapid and prolonged movement of salt water upwards. Further, a spread of salinity took place, owing to an extension of the region where saturation reached the ground surface.

Luken (1962) reported that in an area in southeastern Saskatchewan, where patches of saline soils occur in an undulating to rolling topography on glacial till, soil salinization is neither as serious nor as extensive on grassland as it is on cultivated land. He assumed that fluctuations in the height of the water table, which are related to soil salinization, were accelerated by farming practices such as summer fallow with increased water runoff and erosion. With an increased cultivated acreage and a decreased pasture acreage, the rates of water use by plants were lowered. This resulted in higher rates of runoff.

Classification of Salt-Affected Soils

Alkali soils throughout the world are extremely variable (Kelley, 1951). Almost every conceivable combination of conditions has probably existed at one place or another since soluble salts first accumulated there. In different localities, the soil conditions, stages of soil development, and parent materials were all probably extremely variable before soluble salts first accumulated (Kelley, 1951).

Raychaudhuri (1964) states that "saline soils in India are recognized by extensive white, greyish-white, or ash-colored fluffy salt deposits on the soil surface."

The single distinguishing characteristic of saline soils according to Richards (1950) is soluble salt. He classifies a saline soil as having a saturation extract with an electrical conductivity of more than 4 mmhos./cm. at a temperature of $25^{o}C$. An alkali soil, as classified by Richards (1950), has an extensive degree of saturation with exchangeable sodium, either with or without appreciable amounts of soluble salts being present.

Saline soils represent the first traces of alkalization and correspond to solonchak soils described by Vilenskii (1957). In Handbook 60, "saline" is used in connection with soils for which the conductivity of the saturation extract is more than 4 mmhos./cm. at $25^{o}C$. and the exchangeable sodium percentage is less than 15. The bulk of the salts are sodium salts combined with certain quantities of magnesium salts. The most common anions are chloride, sulfate, and carbonate, nitrate only exceptionally, usually in places where there is organic matter decomposition (De Sigmond, 1938).

Nitrate solonchaks are reported by Molodtsov (1961) to be

characteristic of the desert-steppe and the desert zones of central Asia. Morphologically, the profile of a nitrate solonchak is characterized by an absence of clearly defined horizons. A thin brittle crust occurs and is underlain by a poorly defined salt horizon. The salts are relatively evenly distributed throughout the soil profile.

As a result of differences in salt solubilities in ground water and in the soil solution, maximum accumulations of individual salts occur in different horizons (Vilenskii, 1957). The most readily soluble salts, particularly chlorides, accumulate on the surface, the less readily soluble salts, such as gypsum, lie below, with calcium carbonate at still greater depth (Vilenskii, 1957; Eremin, 1953).

The morphology of a saline soil, according to De Sigmond (1938) usually resembles that of the original soil from which it formed, or is structureless (De Sigmond, 1938). The former would correspond to a saline brown, saline dark brown, saline black, or saline dark grey in the Chernozemic order, or to a saline gleysol in the Gleysolic order of the Canadian soil classification system. The structureless soil would correspond to a saline regosol in the Regosolic order of the Canadian classification system (N.S.S.C.C., 1963).

Sub-types of saline soils as given by De Sigmond (1938) are as follows:

Saline soils containing:

(1) mostly or only sulfates.

(2) mostly or only chlorides.

(3) sulfates and chlorides.

(4) sulfates and carbonates.

(5) chlorides and carbonates.

(6) sulfates, chlorides and carbonates.

(7) mostly soda (sodium carbonate).

Because of their high solubilities, salts move easily in the soil, both vertically and horizontally (De Sigmond, 1938). Consequently, there may be great variations in salt contents of soils within a relatively small area.

Saline alkali soils have electrical conductivities of saturation extracts of more than 4 mmhos./cm. and exchangeable sodium percentages of more than 15 (Handbook 60). These soils correspond to the salty alkali soils of De Sigmond (1938), which are formed through the action of sodium salts, when the adsorbing complex is saturated by a quantity of sodium ions sufficient to considerably increase the dispersion of the colloids. This effect is not appreciable as long as there is an abundant quantity of sodium chloride or sodium sulfate in the soil. However, when the amount of exchangeable sodium exceeds 10 to 15 percent of the total exchangeable cations, the dispersing effect of the sodium ions becomes appreciable. This soil then becomes less and less permeable with the advance of salt leaching.

These soils are often structureless, but some have eluvial and illuvial horizons with definite structures. The former would correspond to saline regosols in the Canadian soil classification system, while the latter would correspond to solonetz soils in the Solonetzic order of the Canadian classification system. (N.S.S.C.C., 1965).

Saline-alkali soils sometimes contain gypsum (Handbook 60). When such soils are leached, calcium dissolves and the replacement of exchangeable sodium by calcium takes place concurrently with the removal of excess salts.

"White alkali" soils contain only neutral salts, chiefly sodium chloride and sodium sulfate, and a white efflorescence is produced on the soil surface. "Black alkali" soils contain soda (sodium carbonate) as well as neutral salts. If the soils are humic, the soda dissolves the humus, and produces a brown efflorescence on the soil surface (De Sigmond, 1938).

Except when gypsum is present in the soil or the irrigation water, the drainage and leaching of saline alkali soils leads to the formation of nonsaline alkali soils (Handbook 60). Electrical conductivities of saturation extracts of nonsaline alkali soils are less than 4 mmhos./cm., and exchangeable sodium percentages are more than 15 (Handbook 60). These soils correspond to leached alkali soils by De Sigmond (1938), which occur where the level of ground water is lowered, though only periodically, or where saline ground water is drained off, and the water-soluble salts are leached out. As the soil is continuously re-wetted and drained, the adsorbing complex loses no sodium, the dispersivity of the soil constantly increases, and a solonetz forms. This soil would correspond to solonetz soils of the Canadian soil classification system (N.S.S.C.C., 1965).

During dry periods, the soluble compounds, which are leached down but not washed out, will rise again to a certain level through capillary action. Though sodium salts follow closely the movement of soil moisture, less soluble salts, such as calcium carbonate and calcium sulfate, follow the sodium salts more slowly in proportion to their decrease in solubility. When downward leaching occurs, calcium sulfate penetrates deeper than calcium carbonate, which is leached from above, and when soil solutions move upward, calcium sulfate rises

higher than calcium carbonate. For this reason, in the subhorizons of leached alkali soils, gypsum concentrations are often higher in the profile than lime concentrations. This phenomenon is substantiated by Eremin (1953), who stated that "easily-soluble chlorides and sulfates are nearer to the surface than the carbonates."

Morphologically, a leached alkali soil has a well-developed hard, columnar, illuvial B horizon.

As leaching continues, sodium adsorbed on the exchange complex becomes hydrolyzed, and is replaced gradually by hydrogen, which occupies the exchange positions on the complex in constantly increasing amounts. The result is that the original alkaline reaction is replaced by an acid reaction. The resulting soils that form have been referred to by De Sigmond (1938) as degraded alkali or "soloti" soils. These soils are characterized by an absence of lime, and the low pH's result from exchangeable acidity. The physical properties, however, are dominated by the exchangeable sodium and are typically those of non-saline alkali soils(Handbook 60).

Morphologically, the A horizon may be divided into two subhorizons, an upper Ah and a lower Ae horizon, which shows characteristics similar to the Ae of the podzol soil. The columnar structure of the B horizon is no longer as distinct as that of the solonetz, and breaks up into nut-like peds (De Sigmond, 1938). These soils would correspond to the solonetz and solod soils of the Canadian soil classification system (N.S.S.C.C., 1965).

Regraded salty alkali soils, according to De Sigmond (1938) are leached and degraded alkali soils which are resalinized as a result of a rise in the water table. The morphological characteristics of the

the original alkali soils are rendered less distinct by the intrusion of salty solutions, but the characteristic structures are still discernible. These soils are not recognized in the Canadian soil classification system.

Saline and Alkali Soils in Different Countries of the World

Saline and alkali soils occur in many countries of the world. The features that are associated with nearly all of these saline and alkali soils are:

(1) arid to semi-arid climate.

(2) high ground water level.

(3) inadequate surface or subsurface drainage.

A review of some saline and alkali soils, found in various countries of the world, follows.

A. Canada

The climate of Saskatchewan is semi-arid to dry subhumid (Dodd and Rennie, 1964). Larger, more coherent belts of saline soils occur in the arid parts of the province than in more moist regions, according to Luken (1962).

Dodd and Rennie (1964) report that most of the saline soils in Saskatchewan are imperfectly or poorly drained. However, they go on to say that in some areas, well-drained soils have become salinized through seepage or as a result of upward movement of salts from saline subsoils, following periods of excessive precipitation. Luken (1962) and Ballantyne (1964) also feel that a succession of wet years may have contributed to an increase in soil salinization in many Saskatchewan soils.

Luken (1962) and Ballantyne (1963) studied salinization in some glacial till soils of Saskatchewan on undulating to strongly rolling

topography. Salinization in the areas studied appears on sides of or near bases of slopes, usually but not always near sloughs (Ballantyne, 1963). Luken (1962) feels that where the glacial drift is comparatively thin, the underlying marine shale bedrock is important with respect to soil salinization and alkalization.

Water levels in sloughs in the area studied are generally dependent upon precipitation, as a result of the low permeability of the subsoil till (Luken, 1962). Luken feels that factors such as topography and its influence on water runoff, and vegetation, or more general, land use, have played a significant role in the occurrence of soil salinity in the described areas. He states that "the occurrence of salinization seems to have originated primarily from temporary water tables and capillary movement of water upwards and its subsequent evaporation. This is indicated by maximum salt concentrations which appear at shallower depths in less elevated profiles on slopes.

Ballantyne (1963) proposed two possible explanations for increases in salinity around sloughs. They were:

(1) Water could move out laterally from sloughs through leached horizons of profiles near the sloughs. This water could cause salts of unleached horizons of profiles, farther away from the sloughs, to move up to the surface.

(2)Excess rain would saturate the soil, even on knolls, and this moisture would move down slope within the soil. Below the point of a reduction in slope, water movement would slow down, causing a concentration of moisture. This would slowly drain down, but some could also move upward through capillary rise, with subsequent evaporation.

Ballantyne (1963) also noted that sodium, and to a lesser extent,

magnesium concentrations increase at faster rates than other ions as the salt content increases in the soil.

The nature and distribution of saline soils in Manitoba have been summarized by Pratt (1954). He divided the province into four geographical regions, and saline soils are found in three of them.

The soils in the western upland region of Manitoba are developed on mixed bouldery till containing considerable amounts of shale in some parts. Shallow deposits of lacustrine and deltaic materials, over the till, occur within the area. Salinized soils are also common in the till area of this region, where undrained depressional areas are common. These act as local catchment basins for runoff water and subsurface lateral seepage from surrounding higher land. In wet spring seasons, and during periods of high rainfall, these basins are flooded. As a result of high water tables or impeded internal drainage, percolation of water into the soil is retarded, thus permitting considerable surface evaporation to occur. As a result, soluble salts from minerals in surrounding soils are deposited on the soil surface.

Large areas of strongly salinized soils occur in the lacustrine clay area. Soils here act as a catch basin for runoff water from Turtle Mountain and the adjacent plain. The internal drainage of these soils is very slow.

Soils of the Souris Basin and Assiniboine Delta region are developed on medium-textured lacustrine and sandy deltaic materials. Soils on these lacustrine and delta deposits are highly permeable and the ground water is very low in soluble salts. Small acreages of saline soils occur where the internal drainage is impeded by a finer-textured substratum of clay loam lacustrine deposits or bouldery till.

Soils on river and lake terraces occur on flat topography with salinized soils predominating in micro-depressions where the internal drainage is impeded by changes in texture within the profile.

Soils on eroded river channels are developed on clay deposits from weathered shale. These are highly impervious, and because of their position, are subject to swamping. Also they are salinized over the whole area.

Very strongly salinized soils occur in some positions of the Agassiz Basin and lowland region, where bouldery till and ridge and swale topography predominate. The salinized soils result from the presence of saline springs or surface gypsum deposits.

Salinized soils are very common in areas where clay sediments form a shallow covering over till deposits. The topography is flat with some micro-relief and because of slow internal drainage, soils in low-lying areas are often covered with water for long periods in the spring and after heavy rains. Only small quantities of water percolate into the soil, with the major portion evaporating from the surface, leaving behind salts dissolved from soils on surrounding higher land.

Soils developed on sand, silt, and clay lacustrine deposits contain accumulations of soluble salts in surface horizons where conditions of poor drainage exist. Soils of the Agassiz Basin and lowland region, that have developed from clay overwash from Cretaceous shales, contain high percentages of bentonitic clay, which is very impervious to water.

B. United States

Studies of salt affected soils have been conducted in the northern Red River Valley of North Dakota by Benz et al. (1961), Sandoval and Shoesmith (1961), Sandoval, Benz and Mickelson (1964), Benz et al. (1964), and Sandoval et al. (1964). The climate of this area is dry subhumid

with an annual precipitation of less than 20 inches (Benz et al., 1961; Sandoval et al., 1961).

The geology of the area includes glacial drift 100 to 400 feet thick, overlain by lacustrine sediments near the Red River and by deltaic sediments near the western edge of the valley. Between these two areas, glacial drift is exposed (Benz et al., 1961). Most of the soils of the area are Chernozemic (Sandoval et al., 1961). The topography is very subdued in the study area, the slope being 2 to 3 feet per mile near the Red River, and 15 to 20 feet per mile at the western edge of the valley. Surface drainage is very poor (Benz et al., 1961).

Most of the saline lands are on deep lacustrine sediments, some of which are more than 100 feet thick (Sandoval et al., 1961). However, in many acres of the problem area, glacial drift is at or near the surface (Benz et al., 1961). Frequently, several feet of coarse-textured material occur over compact fine-textured till (Benz et al., 1961; Sandoval et al., 1961). The salinity problem is more variable here than elsewhere (Sandoval, 1961). This agrees with Matzek (1955), who states that "differences in permeability among soils and parent materials often have more profound effects on the leaching of soluble materials than have small dissimilarities in topography."

The salinity problem in the Red River Valley is associated with high water tables, poor drainage, and artesian conditions (Sandoval et al., 1964). Precipitation is the major contributor to the water table levels. Matzek (1955) also attributes the accumulation of soluble salts in solonchaks of North Dakota to a high water table. He states that "the upward capillary movement from a high water table far exceeds the downward movement of water in the soil, and that soluble

salts can accumulate in surface layers even though soluble salt content of the parent materials is low.

Free-flowing artesian wells are prevalent in the Red River Valley the water sources being the Dakota sandstone aquifer, and sand and gravel lenses located in the glacial drift (Benz _et al._, 1961). These lenses probably receive water through interconnections with the Dakota sandstone.

In the area of highest salinity (the lacustrine area), the glacial drift lies directly on the Dakota sandstone formation (Benz _et al._, 1961). A similarity exists in the composition of the deep artesian waters and shallow ground waters from the glacial till areas, indicating that artesian sources are the principal contributors of salt to the ground surface in the till (Benz _et al._, 1961). These artesian waters are highly mineralized. Data indicates a relationship between high water tables and the areas of highest salinity (Benz _et al._, 1961).

Over much of the area, where slight or moderate salinity is present, an undulating micro-relief accentuates the problem of poor drainage and soil salinity (Sandoval _et al._, 1961; Benz _et al._, 1964). The micro-relief consists of a series of intersecting ridges and depressions, seventy-five to several hundred feet apart, and with elevation differences of 1 to 2 feet (Benz _et al._, 1964). These small differences in elevation result in good growth to complete failures of most crops (Sandoval _et al._, 1964). The ridges are high in salt and the depressions are relatively nonsaline (Benz _et al._, 1964). Runoff from the ridges is frequently impounded, resulting in more leaching in the depressions. Also, upward movement appears greater than downward movement on the ridges, resulting in salt accumulations (Sandoval _et al._, 1961).

In an area studied by Fireman and Reeve (1948) in the Payette River Valley of Idaho, salinity occurs as small irregular bare spots scattered throughout cultivated fields. The water table is at 3 to 6 feet from the surface over the major portion of the problem area, and coarse river gravel, providing free lateral ground water movement, underlies much of the area.

C. Russia

Eremin (1953) states that "soil salinity is caused by the nearness of ground water to the soil surface." This seems to be the common factor discussed by Russian workers in studies of soil salinization, as evidenced by Muratova (1958), who also states that "salt accumulation in soils is affected chiefly by ground water." She goes on to say that the extent of ground water action on the soil depends upon the depth to the water table.

According to Sukhachev (1958), salts found at the periphery of the Sokh alluvial fan are derived from ground water currents which originate in higher zones, where atmospheric precipitation and surface runoff are absorbed and the salts washed out. They also come from strongly mineralized water flowing in from artesian horizons of lower strata. He states that "the rate of inflow of ground water, containing dissolved salts, and the height of capillary rise of water below the evaporating surface are determined by the interaction of hydrostatic pressure and the factors which oppose it. These factors are:

(1) resistance of the soil.

(2) downward filtering currents.

(3) evaporation.

(4) transpiration.

(5) losses to adjoining soil areas.

Slight or moderate soil salinization has been caused by a local outflow of ground water along sandy drainage layers during irrigation.

Muratova (1958) states that "soluble salt accumulation in parent material and ground water is explained by a combination of the physical and geographic conditions of:

(1) levelness of location.

(2) high temperature and evaporation.

(3) absence of natural drainage and runoff."

According to Truss (1959), under central Baraba conditions, salt accumulation in the soil is chiefly a result of soil formation processes, past and present, and mineralization of plant residues. He states that "the salinization rate of soils and ground water is intensified in the direction of a common slope gradient, and consequently there is a clearly-expressed degree of soil salinization based on topography." The nonsalinized and slightly-salinized soils, being better drained mineral soils, are situated at higher elevations (Truss, 1959). Truss goes on to say that salt accumulation in soil and the formation of salinized soils on individual elements of relief are brought about by ground waters being close to the surface and by local runoff waters, as well as by climate and geomorphological conditions, geological structure, water-logging, and vegetation.

Muratova (1958) states that "the differentiation of salts between soils and ground water is very widely manifested in nature, the redistribution of salts along the soil surface, vertical profile, and parent material being explained by differences in:

(1) salt solubilities.

(2) exchange reactions.

(3) activities of living organisms.

(4) drainage conditions."

This causes salt accumulation in ground water and soils to develop by stages: from slight to intense, and from seasonal spottiness to continuous salinization.

"The salinity of ground water of the Bug flood plain," as stated by Pekatoros (1960), "is higher than at its source." The increase in mineralization results primarily from ground water losses through evaporation, where discharge is insignificant because of poor drainage.

Soil formation in the Terek River delta, according to Sokolovskiy (1960), is closely associated with geologic activities of flooding by the Terek River, and past transgressions and regressions of the Caspian Sea. He states that "the advance of the sea caused a rise of the ground waters, an increase in their mineralization, and an intensification of salinization of the soils." The retreating sea left numerous solonchak lagoons and lakes, which to this day serve as the main cause of salinization in the coastal zone of the delta. Water table levels remain high, as there is an absence of natural drainage and a blocking-up of ground water flow by the sea. Sokolovskiy (1960) states that "local movements of salts along micro-relief and in the soil profile are much more rapid than the process of salt accumulation in the delta, the rate depending upon atmospheric precipitation and the irrigation regime. These movements are so great that they can be determined by periodic soil sampling. The low micro-relief forms are subject to comparatively high salinization.

In sodic soil salinization in the Soviet Union, the most common sources of sodium carbonate in ground waters and soils, as listed by Egorov (1964), are as follows:

(1) Disintegration processes of various rocks which are periodically losing lime or which have lost large parts of their calcium during

previous decay.

(2) Solutions of sodium hydrocarbonate gushing from depths under favourable geological and hydrogeological conditions.

(3) The soil biological theory of sodium carbonate formation, based on the reduction of sodium sulfate, which is taking place on the surfaces of super-humid soils or in ground waters.

(4) Vegetable origin of sodium carbonate where plants, after utilizing the sulfur of sulfates, form sodium carbonate (this hypothesis has indirect proof that has not yet been experimentally verified).

D. India

Raychaudhuri and Datta Biswas (1954) state that "saline and alkali soils are common throughout India in all climatic zones." They further state that "injurious salts are present in the soil profile and may become evident in surface layers under the following conditions:

(1) arid or semi-arid climate.

(2) impervious subsoil, or hardpan.

(3) temporary abundance of humidity in the soil interspersed with dry periods."

Alkali soils are impervious at the surface or at some depth. These profiles are generally associated with Kankar (calcium carbonate concretions) or a definite hardpan, which restricts the upward movement of water by capillary action and the downward flow of water by percolation under the flow of gravity. In the Punjab, salinity and alkalinity occur in canal-irrigated areas where there has been a marked rise in the subsoil water table. In the northern region of Bihar, where a humid climate exists, scattered saline and alkali patches occur, probably as a result of impeded movement of soluble salts in the subsoil.

Banerjee (1959) described some salt-affected soils of Canning, West Bengal. He states that "the two dominant agents in soil formation in this region are rain and sea water." These soils have been subjected to the influence of sea water at some time in the past and so have been rendered saline or saline-alkali. Where sea water still has some access to land, as a result of lower topography, proximity to land, or restricted drainage causing a high water table, the resultant soil solution is rich in salt.

E. Pakistan

The development of soil salinity along the banks of the Indus River in Pakistan is attributed to low rainfall, excessive evaporation during hot and dry periods, and lack of subsoil drainage during the inundation season (Raychaudhuri and Datta Biswas, 1954).

F. Afghanistan

Raychaudhuri and Datta Biswas (1954) report that saline and alkali soils are common in all types of soils of Afghanistan, belonging to grey, semi-desert, and steppe groups developed under the very dry climate of the country. These soils are characterized by impeded drainage and high water tables, varying from 1 to 2 meters below the soil surface.

G. Australia

In an area at Tintinara, south Australia, studied by Jackson, Blackburn and Clarke (1956), the climate is characterized by hot dry summers and cool wet winters. The soils of the area generally have sandy surfaces and fine-textured subsoils at varying depths, with columnar structural features. High contents of soluble salts are common in these soils, and especially in the subsoils, particularly where ground water occurs close to the surface. Very marked changes

occur in soil salinity during the year. There is a dominant upward flow of water and dissolved salts in dry periods, and a dominant downward flow in wet periods.

Soils with similar depths to ground water and with equally-saline ground waters, but with different profile features, vary greatly in salinization (Jackson, Blackburn and Clarke, 1956). Differing salt concentrations at various sites result from:

(1) differences in soil morphology,

(2) varying depths to ground water,

(3) different ground water salinities,

(4) differing densities and species of plants growing on the sites.

These workers found that the maximum rainfall during the year corresponded with the period of greatest surface salt concentration.

In a study of salty soils of the Mirrool irrigation area in New South Wales, Groenewegen (1961) found that in the more saline profiles, the largest portion of the soluble salts in the surface soil horizons was derived from salts initially present at greater depths.

H. Egypt

Schoonover, El Gabaly and Hassan (1957) report that many areas in Egypt show evidence of salinity and alkalinity which appear to be localized and associated with high water tables. The climate of Egypt is arid with little rain, thus providing no effective leaching of the soil.

El Gabaly and Naguib (1964) studied irrigated soils in the Nile delta and valley. They concluded that the depth to ground water contributes more to the salinization of the soil surface than does the salinity of the ground water.

I. Iran

Antipov-Karatayev and Kisilova (1962) describe two types of soil salinization in two areas on the Iranian Plateau in the piedmont plains on the southern slopes of the Elburz mountain range.

The Garmsaar Plain area consists of stratified material which gradually changes to finer-textured material with proximity to the desert plain. It is toward the desert plain that the ground water level rises and its degree of mineralization increases. Its mineralization is determined by the salt composition in Tertiary rocks, which are rich in neutral salts. The piedmont areas of the Elburz Range are composed of these Tertiary rocks.

The Gezelhezar area of depressional topography is a typical zone of ground water seepage which drains from the Elburz range. Here, geological deposits consist chiefly of Paleozoic, Upper Jurassic, and Cretaceous limestones and dolomites. Therefore, ground water in Gezelhezar is more weakly mineralized than similar water in Garmsaar. The soil material in the Gezelhezar area is heterogeneous and stratified, consisting mainly of fine clay loams.

J. Iraq

Harris (1960) studied saline soils in the Kirkuk Plain of northern Iraq. Gypsiferous alluvium underlies most of this area at varying depths, usually less than one and a half meters from the surface.

The accumulation of salts in the soil is primarily a result of high water tables. Fresh ground water acquires salts as it passes through rocks, and also by dissolving the gypsum beds through which it passes.

Areas of former irrigation have higher salinity than surrounding

areas, probably as a result of high water tables induced by irrigation. Also, areas having high water tables are coincidental with saline soils.

K. Israel

Ravikovitch, Koyumdjisky and Dan (1960) report that the main causes of salt accumulation in the soils of the western and central valleys of Yizreel are:

(1) high water tables,

(2) heavy soil textures.

High exchangeable sodium contents result.

L. Bulgaria

The regime of the ground water in the Frakia Depression of Bulgaria is greatly affected by its movement and the textures of the materials through which it travels (Vodenicharov, 1959). Vodenicharov (1959) states that "the ground water initially traverses crystalline strata at depths of 10 to 15 meters and is very slightly mineralized, but when it crosses Pliocene deposits, which are rich in sodium and other salts, it picks up these salts in heavier concentrations. Later when it hits impervious layers, it emerges at the soil surface and deposits salts through evaporation." Solonetzic processes are characteristic phenomena in the Frakia Depression.

M. Hungary

Darab and Szabolcs (1960) state that "secondary salinization of soils occurs in irrigated zones of the Great Hungarian Plain, where water table levels are near the soil surface.

N. Rumania

Florea and Stoica (1958) report a close link between the degree of soluble salt accumulation and the depth to the ground water table in

soils of the northwest Rumanian Plain. The degree of salt accumulation increases with a decrease in the depth of the water table and with diminishing drainage. Consequently, accumulation of readily-soluble salts occurs in low relief areas and depressions where high rates of ground water evaporation occur, especially during the dry season of summer. Thus, in soils and subsoils of depressions, salts of ground water from neighboring areas accumulate.

O. Yugoslavia

Miljkovic, Ayers and Eberhard (1959) state that "saline and sodic soils in Yugoslavia often occur in slight depressions, are usually underlain by high water tables, and have been subject to flooding." They were once covered by the Pannonian Sea.

P. China

Most saline and alkali soils owe their origin to natural drainage conditions and are found in areas of varying topography where there is a high water table or an actual seepage of water at the soil surface (Raychaudhuri and Datta Biswas, 1954).

In regions of semi-arid climate and in more humid districts along the sea coast, saline soils occur in places where the water table is high and the subsoil water contains at least small amounts of soluble salts.

Saline deltaic soils of eastern Kiangsu originated from the effects of high tides and high levels of subsoil water, brackish in nature. These soils are highly stratified, and are characterized by greatly varying conditions of permeability and capillarity.

Saline soils of the northern Chinese plains are characterized by the presence of sodium chloride, sodium sulfate and sodium bicarbonate

with small amounts of sodium carbonate in spots (Raychaudhuri and Datta Biswas, 1954). The drainage conditions of these soils are very poor, and a brackish subsoil water table lies within 2 or 3 meters of the soil surface. Yegorov (1961) also reports sodium carbonate salinization of soils in Sinkiang.

Saline and alkali soils of Manchuria occur on a nearly flat plain where drainage conditions are exceedingly poor. There are many shallow lakes and ponds where salt accumulation has taken place (Raychaudhuri and Datta Biswas, 1954).

Q. Java

Raychaudhuri and Datta Biswas (1954) state that "a really arid climate is non-existent in Java, where rainfall everywhere exceeds evaporation." In spite of this, soils containing injurious quantities of soluble salts, are found.

Low-lying soils in the immediate neighborhood of the sea, or soils farther inland, where brackish water is present in excessive amounts, are characterized by the presence of sodium chloride in quantities injurious to crop growth.

Farther inland, accumulations of injurious quantities of sodium chloride, several meters above sea level are found, and are said to be caused by saline springs which emerge from Neogene deposits.

R. Spain

Ayers *et al*. (1960) studied saline and sodic soils in different regions of Spain. Marine deposits in the Aragon and Cataluna basin include clays, sandstone, shales, limestone, and gypsum. On land that is rolling and broken, salinity is often evident on slopes and in valleys. Rainfall and seepage from irrigation percolate down through the soil,

collecting salts during infiltration. When this water meets horizontal layers of less permeable material, water tends to move laterally and approaches the surface on slopes and in valleys. Poor drainage and high evaporation result in concentrations of salts and the formation of saline soils. Also, gypsum is scattered throughout this region, and is frequently exposed where level uplands break off into valleys.

The lands of the Andalucia region have been flooded by sea water because of high tides and high winds on the Atlantic, and have also been inundated by floods from rivers, and runoff from adjacent hills. Surface and internal drainage are poor, with water tables at depths of 1 to 2 meters, depending upon the elevation of the land, the season of the year, and the levels of water in the rivers. These recent alluvial soils are primarily fine-textured and many of the subsoils contain visible quantities of gypsum. Most of the soils are saline or saline-sodic, the natural vegetation being typically halophytic. It is quite variable and can be correlated with salinity and the depth to the water table.

Scattered areas of saline soils occur in the Alicante region as a result of localized conditions of poor drainage, high water tables, and high rates of evaporation.

Areas of salty soils occur in central Spain, indications being that the salinity problem is increasing, and noticeably so since 1934.

Previous Work in the Study Area

A. Geology

The two main geologic formations that occur in the study area are the Paskapoo Formation and the Edmonton Formation (Allan, 1943) (map 4). The Edmonton Formation extends into the study area from the

east (map 4) coming about as far west as the 113-degree line (Allan, 1943). The Paskapoo Formation predominates in the rest of the study area.

The Edmonton Formation, as described by Williams and Dyer (1930), Russel and Landes (1940), and Allan (1943), consists of non-marine, highly calcareous, thick series of alternating sandstones and shales, with some thin beds of pure bentonite present. The sandstones are usually hard, massive, and medium-grained, and the beds are lenticular in shape. The shales are friable, and commonly contain appreciable contents of sand. Crossbedding and irregular bedding are common structural features of the formation, and the usual color is greenish-grey, with grey and brown shales also occurring. The Edmonton Formation varies in thickness, being about 400 feet thick along the Little Bow River. Williams and Dyer (1930) state that "large numbers of brackish water and marine shells are found at one horizon, a little more than half-way up in the formation, indicating that the sea must have invaded the land during at least one period during deposition."

The Paskapoo Formation is of fresh water deposition (Allan, 1943). It is composed of thin alternating beds of sands, clays, and sandy clays (Williams and Dyer, 1930) with irregular indurated beds, weathering into rounded outcrops of the badlands type (Russell and Landes, 1940). In the lower portion of the formation, the beds are nearly all soft and incoherent, but toward the top, harder beds of sandstone occur (Williams and Dyer, 1930). The thickness of the Paskapoo Formation averages about 1000 feet, according to Williams and Dyer (1930).

Farvolden (1963) states that "southern Alberta is underlain by

shale and impermeable sandstone, and that the only aquifers capable of yielding large supplies of ground water, apart from gravel bars along present-day rivers, are the sand and gravel deposits associated with bedrock channels." When these sand and gravel deposits are well sorted and occur below the water table, they are excellent aquifers. Bedrock channels have been plotted in southern Alberta by Farvolden (1963) and Geiger (1965), and Geiger has drawn a map of the bedrock contours of map sheet 82H and portions of 82I, J, and G of southern Alberta. A number of preglacial drainage channels are shown in the Vulcan area, although Geiger (1965) states that "interpretation of the most recent preglacial drainage in this area is very difficult."

According to Farvolden (1963), the present-day surface is nearly coincidental with the bedrock surface over most of the southern half of Alberta. Major upland areas are underlain by bedrock, and the major bedrock channels coincide with broad depressions in the present land surface. A large number of narrow glacial meltwater channels have been incised into the surficial deposits, and in many instances, into the underlying bedrock. Most of these channels are now abandoned except for intermittent streams, but some still carry permanent streams. There is evidence that the Alberta plains region is slowly recharged by local precipitation.

The surficial geology of the Vulcan area is mainly glacial drift (Wyatt and Newton, 1925) in the form of ground moraine (Allan, 1943). This drift remains largely as it was deposited by the glaciers, with resorting by postglacial streams of much of the surficial material since it was originally deposited, being evident (Wyatt and Newton, 1925).

The glacial deposits in the study area, according to Allan (1943) and Wyatt and Newton (1925) have been derived from two sources. These

are as follows:

(1) Mountain or alpine glaciers originating within the Rocky Mountains and proceeding eastward over the foothills and plains, carrying rock debris from rock formations within or possibly west of the front ranges of the Rocky Mountains.

(2) Keewatin or continental glaciers originating in the vicinity of the Hudson Bay, bringing with them a very different kind of rock debris, derived from Precambrian rocks in the Canadian Shield, together with rock material from the plains over which the glaciers passed, and large proportions of materials weathered from the underlying sandstones and shales.

B. Soils

Part of the study area is within the Macleod soil survey sheet, which was published in 1925 by Wyatt and Newton, and part is within the Blackfoot soil survey sheet, which was published in 1942 by Wyatt, Newton, Bowser and Odynsky, and revised in 1960 by Peters and Bowser. A portion of the study area was remapped by the Alberta Soil Survey when the southern half of map sheet 82I was mapped in the summers of 1962 and 1963. This most recent work has not yet been published.

Most of the soils of the Vulcan area fall into the Chernozemic order of the present Canadian soil classification system. Wyatt et al. (1942) state that "at various places throughout the area, sandstone bedrock is very close to the surface, sometimes to within plow depth." Wyatt and Newton (1925) state that "in certain places the subsoil is very irregular, ranging from sand, to stony, gravelly, and clay pockets." On the borders of these areas, and near the fine sandy loam areas, the subsoil is often coarser in texture than the surface. Also, in certain areas, there is a thin stratum of sand about 2 to 4 feet below the

ground surface. However, the subsurfaces and subsoils generally are finer-textured than the surface soils (Wyatt and Newton, 1925).

Wyatt and Newton (1925) noted the presence of a number of small lakes occurring in depressions. Most of these dry up during the summer months of drier seasons, but contain water all year-round during seasons of heavier rainfall. In certain areas, many have become "alkali" because of the absence of outlets, together with relatively high salt content of the surrounding soils. Wyatt and Newton (1925) state that "shales are at least one source of salts found in the surrounding soils, and are the main source of gypsum."

Wyatt et al. (1942) have observed that, along some drainage ways, the soil may be quite saline, and may also contain some Solonetzic patches. They state that "in part of the area, particularly between Vulcan and Brant, natural seepage often brings salts to the surface." These salt concentrations can be noticed on hill slopes and along road cuts.

Summary Of The Literature Review

The main factors that contribute toward soil salinization are as follows:

(1) Arid and semi-arid climates.

(2) Poor drainage.

   (a) inadequate surface drainage resulting from low relief.

   (b) inadequate internal drainage where coarse-textured surface soils overlie fine-textured substrata.

(3) Temporary or permanent high water tables.

(4) Variations in topogratphy.

Most workers report that soil salinity is most pronounced in low

relief or depressional areas of a landscape, although salinity has been reported on ridges in an area of undulating micro-relief.

(5) Ground water seepage.

(a) When the soil surface becomes saturated by excessive rainfall, water a few inches below the surface, may move down slope. Below a point of reduction in slope, water movement slows down and a concentration of moisture results. Some of this moisture moves to the surface by capillary rise, and surface evaporation results in a concentration of salts.

(b) Salinity occurs on slopes and in valleys where ground water flows over impermeable beds that intersect the surface.

(c) Seepage occurs locally where water flows along sandy drainage layers near the surface during irrigation.

(6) Saline springs and artesian conditions.

(7) Upward movement of salts from saline subsoils following periods of excessive precipitation.

(8) Proximity to the sea.

(a) High water tables result from an absence of natural drainage and a blocking-up of ground water flow by the sea.

(b) In some areas, sea water has access to the land as a result of low elevations and high tides. Restricted drainage causes high water tables, and a brackish soil solution results.

III. MATERIALS AND METHODS

Materials

The boundaries of the study area are the southern edge of township 12 to the south, the northern edge of township 21 to the north, the eastern edge of range 23 in the southeast corner of the area, a north-south line approximately in the centre of range 22 in the northeast corner of the area, and the fifth meridian to the west (map 1).

The study area is in the region of the typical short grass prairie (Campbell and Almadi, 1964). The climate is semi-arid, and is subject to extremes of heat and cold, having warm summers and relatively cold winter temperatures (Wyatt et al., 1942). The winter temperatures are subject to fairly rapid fluctuations as a result of chinook winds (Wyatt et al., 1942). Occasionally during the winter, cold air is replaced by warm dry air from the mountains to the west. Sometimes the warm air raises temperatures to 40^{o} or 50^{o}F. Winter temperatures have been 61^{o}F in Calgary, about 50 miles northwest of Vulcan, and 65^{o}F in Lethbridge, about the same distance southeast of Vulcan, as a result of chinooks. Blizzards also occur in this region, resulting from the combination of cold temperatures, high winds, and driving snow.

The average annual frost-free period ranges from 80 to 120 days in the prairie region. The average annual frost-free period over a period of 45 years, up to 1956 at Gleichen, about 40 miles north of Vulcan, was 101 days. During the period of 1951 to 1964, the frost free period averaged 117 days at Vulcan (Climate of Canada, 1960). July is the sunniest month of the year, with total amounts of sunshine, during the month, exceeding 300 hours. The long term monthly average of bright sunshine for the summer months of May through September, at Calgary, is 250 hours. December is the dullest month of the year with total sunshine of less

than 100 hours. The long term monthly average for the winter months of October through April, at Calgary, is 136 hours. There is a tendency for skies to be cloudless or completely overcast on the prairies (Wyatt _et al._, 1942).

Over a large section of the prairies, the total annual precipitation averages less than 15 inches. The prairie precipitation regime shows an early summer maximum, with 60 to 75% of the year's precipitation falling during the crop season of late May to early September (Wyatt _et al._, 1942). Long term records at Calgary show an average annual precipitation of 17.53 inches (Climate of Canada, 1960). Sixty-six percent of this amount falls during the summer months of May to September. Records at Vulcan from 1953 to 1962 show an average annual precipitation of 17.04 inches. Sixty-four percent of this amount falls during the summer. Thunderstorms, frequently accompanied by hail, are common in the prairie region, especially during mid-June to mid-August. Winter snowfall on the prairies averages 30 to 50 inches. The first snow usually appears in late October, and the snow usually disappears in early April. Precipitation on the prairies shows wide variation from year to year. Differences between extreme annual amounts may exceed the mean annual total.

Long term temperature records at Calgary show an average mean temperature for the summer months of May through September of 56°F., and for the winter months of October through April of 26.8°F. The highest temperature recorded was 97°F. during July, and the lowest temperature recorded was -49°F. during February. The average mean summer temperature at Vulcan from 1953 to 1962 was 57.5°F., and the average mean winter temperature for this period was 26.4°F. The highest temperature recorded during this period was 98°F. during August, and the lowest temperature was -31°F. during January and February (Climate of Canada, 1960).

Long term records of wind velocities at Calgary show an average year-round wind velocity of 9.9 miles per hour. The most prevalent wind directinn during the summer months of May to September is northwest. During the winter months of October to April, it is west (Climate of Canada, 1960).

Wyatt and Newton (1925) stated that "the average annual rainfall, prevailing winds, and high amounts of bright sunshine cause high evaporation rates on the prairies."

The natural vegetation in the study area is native prairie grassland (Wyatt and Newton, 1925; Wyatt *et al.*, 1942). The grassland of the area has been designated "mixed prairie" by Moss (1955). The mixed prairie association, according to Coupland (1950) as outlined by Moss (1955), is dominated by six grass species, namely:

(1) *Stipa comata*.

(2) *Stipa spartea*, variety curtiseta.

(3) *Boutaloua gracilus*.

(4) *Agropyron dasystachyum*.

(5) *Agropyron smithii*.

(6) *Koeleria cristata*.

A seventh grass, *Muhlenbergia cuspidata*, is a dominant species in eroded areas. The chief sedge is *Carex eleocharis*. Composites and legumes are the most abundantly represented families of dicotyledons. Numerous forbs are also present, and important shrubs are *Rosa arkansana* and *Artimisia cona.*

Salts occur in high concentrations in the study area in three main types of locations (plate 1), namely:

(1) Along stream courses and drainage channels, around sloughs and in low areas, and seeping laterally away from these areas.

(2) Where Solonetzic soils are present, often in low areas.

(3) Along the bases of slopes or part way up slopes of land where the most common classes of topography are "c" (2 - 5% slope) and "d" (6 - 9% slope).

Salt-affected areas may appear in aerial photographs as white mottled patterns, or they may be recognized by sharp tonal contrasts. Tonal contrasts are caused by vegetational variations, which may in turn result from the detrimental effects of salts upon vegetative growth. Plates 1a and 1b are examples of saline areas observed on air photos.

Observations throughout the study area have shown that the salts are most evident in the spring, shortly after spring runoff has ceased and before farmers have cultivated the land. White salt patches show up in scattered locations in cultivated fields, and resemble patches of snow from a distance. The white salts occur as crusts on the soil surface, coating the peds. In some salt-affected areas of native or seeded grassland, the occurrence of salts may be masked by the vegetation. However, from the detrimental effects of salts upon vegetation, salt-affected areas can be located. In late summer, salt-affected areas may be recognized in the field by the presence of poor or no crop growth.

The three most common soil types that are mapped in the study area are Granum Loam, Lethbridge Loam, and Shallow Lethbridge Loam. These soils are Orthic Dark Browns. Granum Loam is developed on glacial till, Lethbridge Loam on medium-textured lacustrine deposits, Shallow Lethbridge Loam on medium-textured lacustrine deposits with till at a depth of less than 3 feet below the soil surface. The average thickness of the Ah horizons of these soils is 7 inches, and the average depth to the lime horizon is 16 inches. Profile descriptions are shown in table 1.

Plate 1a. Common appearance of saline areas on aerial photographs

Plate 1b. Common appearance of saline areas on aerial photographs

Description of Plate 1a

A. Town of Vulcan.

B. Salts around sloughs and on slopes.

C. Area of Solonetzic soil and salts, along a drainage channel.

D. Salts in depressional areas and along drainage channels.

Description of Plate 1b

A, B, C. Areas of Solonetzic soil.

D. Area of Solonetzic soil, and salts along drainage channels.

Locations of sampling sites are shown in figure 1, and locations of wells, sampled profiles, and deep drill holes are shown in figures 2 and 3. Photos of two of the sampling sites are shown on plate 2.

All soil profiles were sampled in the spring of 1964. The field at site 1, at the time of sampling, was seeded down to tame hay, except for the saline slope where the soils were sampled. This area was left in native grass, and the vegetation became progressively more sparse down slope. The slope faces toward the northwest, and salts occurred sporadically throughout. A 2-inch sand lens occurred at 28 inches in profile 2, near the top of the slope.

The field at site 2 was in summerfallow at the time of sampling. Salts appeared as a white crust on the soil surface in the saline area, where the soils were sampled. The soils were sampled on a northeast-facing slope.

The field at site 3 was seeded down to rape at the time of sampling. White salt patches appeared intermittently throughout the salty area shown in figure 2c. Profile 1 was sampled in an area where a good stand of rape was established, and no salts appeared on the surface. Profile 2 was sampled in an area where white salt crusts were evident, and where growth of rape was restricted. Salts were only slightly evident on the surface, in the area where profile 3 was sampled; however, growth of rape was restricted. Profile 4 was sampled at the bottom of the slope, adjacent to a drainage course, where high concentrations of salts on the surface were evident. The soils were sampled on an east-facing slope. A 2-inch sand lens was observed at the 31-inch depth in profile 2, and 4-inch sand lenses were observed at the 3-inch and 20-inch depths in profile 4.

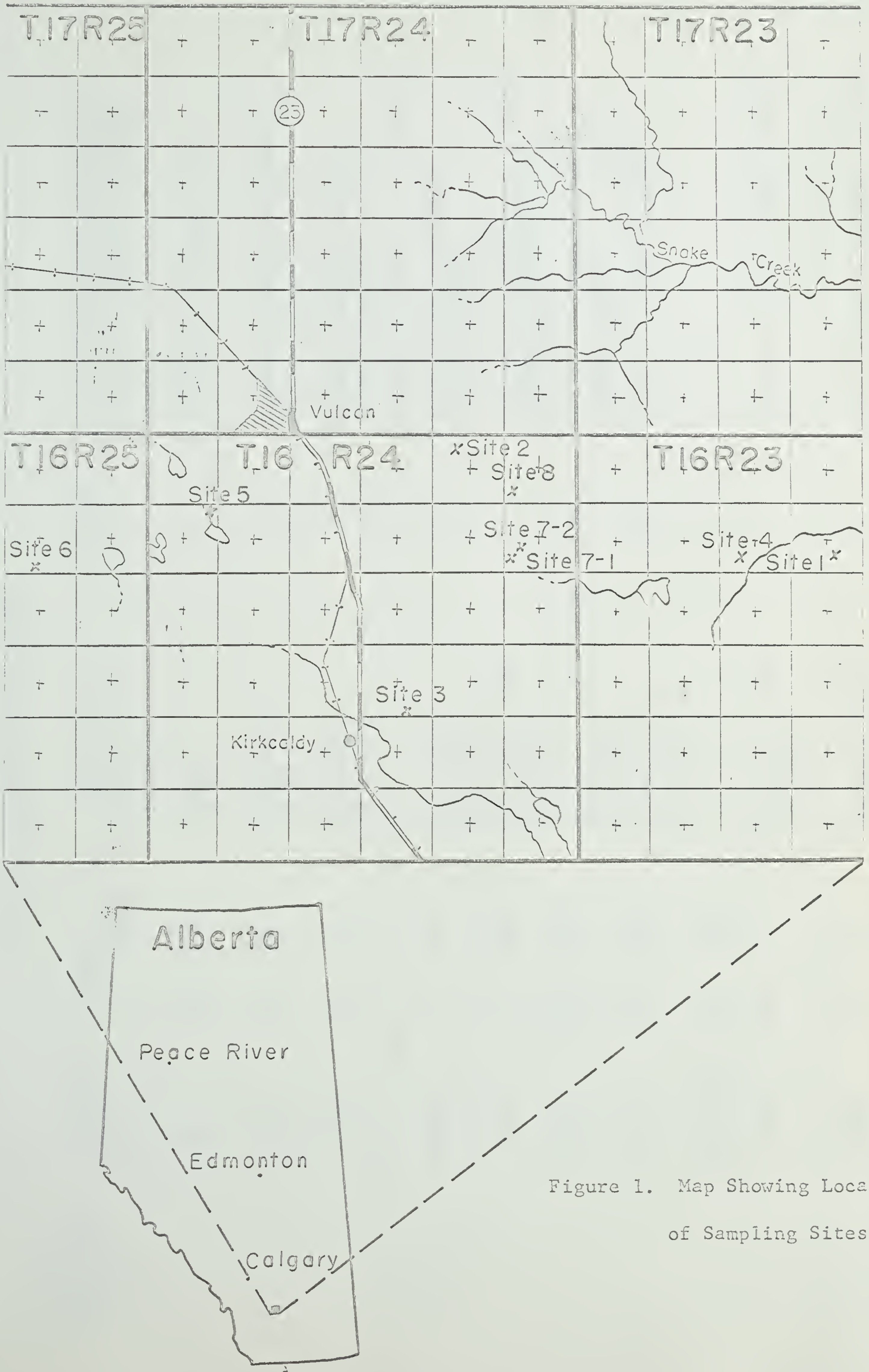


Figure 1. Map Showing Locations of Sampling Sites.

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
1 - 1	Ah	0 - 2½"	Greyish brown 10 YR 5/2	L	Granular, friable, slightly moist
	Bt	2½ - 10"	Brown 10 YR 5/3	L	Prismatic, friable, dry
	Cca	10 - 18"	Light grey 10 YR 7/2	L	Massive to weak prismatic, friable, dry
	C-till	18 - 35"	Pale brown 10 YR 6/3	SL	Massive, fairly friable, slightly moist
1 - 2	Ahsa	0 - 2½"	Dark brown 10 YR 4/3	L	Weak granular, friable slightly moist
	Btsa	2½ - 10½"	Yellowish brown 10 YR 5/4	L	Prismatic, breaking to blocky, friable, slightly moist
	BCsa	10½ - 16½"	Bright yellowish grey 10 YR 6/2	SiL	Massive to weak prismatic, friable, moist
	Cca	16½ - 26½"	Light grey 10 YR 7/1	SiL	Massive, friable, moist
	Sand lens	28 - 30"	-	-	--
	C-till	26½ - 34"	Very pale brown 10 YR 7/3	L	Massive, fairly friable, moist
1 - 3	Ahksa	0 - 8	Greyish brown 10 YR 5/2	L	Weak granular, friable, moist

*Munsell colors
1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
1 - 3 (cont.)	Btksa	8 - 13"	Light brownish grey 10 YR 6/2	L	Prismatic, breaking to weak blocky, friable, moist
	BCksa	13 - 18"	Light brownish grey 10 YR 6/2	L	Massive, friable, moist
	Ccasa	18 - 24"	Light brownish grey 10 YR 6/2	L-CL	Massive, slightly sticky, wet
	C-till	24 - 36"	Light grey 10 YR 7/2	L	Massive, sticky, wet
	C-till	36 - 38"	Light grey 10 YR 7/2	SL	Massive, friable to slightly sticky, wet
1 - 4	Ahksa	0 - 4½"	Dark brown 10 YR 4/3	SL	Massive to weak granular, very friable, moist
	Bmksa	4½ - 9½"	Brown 10 YR 5/3	SL	Prismatic, breaking to weak blocky, friable, moist
	Ccasa	9½ - 15"	Pale brown 10 YR 6/3	L	Massive, breaking to weak blocky, slightly sticky, wet
	C-till	15 - 38"	Very pale brown 10 YR 7/3	L	Massive, sticky, wet
1 - 5	Ahksa	0 - 7"	Grey 10 YR 5/1	SL	Massive, breaking to weak blocky, friable, moist
	Bmksa	7 - 13"	Light brownish grey 10 YR 6/2	SL	Massive, breaking to prismatic, friable, moist

*Munsell colors
[1]N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
1 - 5 (cont.)	Ccasa	13 - 26"	Light grey 10 YR 7/2	SL	Massive, sticky, wet
	C-till	26 - 40"	Pale brown 10 YR 6/3	L-CL	Massive, sticky, wet
1 - 6	Ahkgsa	0 - 4"	Grey 10 YR 5/1	L	Massive, friable, moist
	Bgksa	4 - 10"	Grey 10 YR 6/1	SiL	Blocky, friable, moist
	Ccagsa	10 - 20"	Light grey 10 YR 7/1	SL-L	Massive to weak blocky, slightly sticky, wet
	C lacustrine	20 - 36"	Light grey 10 YR 7/1	CL	Massive, sticky, wet
	C lacustrine	36 - 42"	Light grey 10 YR 7/1	L	Massive, breaking to sub-angular blocky, sticky, wet
2 - 1	Ap	0 - 6"	Dark brown 10 YR 4/3	SL	Weak granular, very friable, moist
	Bt	6 - 12"	Yellowish brown 10 YR 5/4	L	Prismatic, friable, moist
	BC	12 - 14"	Yellowish brown 10 YR 5/4	L	Massive, breaking to weak prismatic, friable, moist
	Cca	14 - 24"	Pale brown 10 YR 6/3	L	Massive, friable, moist

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
2 - 1 (cont.)	C-till	24 - 36"	Light grey 10 YR 7/2	L	Massive, fairly friable, moist
	C-till	36 - 48"	Pale brown 10 YR 6/3	L	Massive, fairly friable, moist
2 - 2	Ap	0 - 5"	Dark brown 10 YR 4/3	L	Weak granular, very friable, moist
	Bmsa	5 - 8"	Yellowish brown 10 YR 5/4	L	Weak prismatic, friable, moist
	Ccasa	8 - 20"	Very pale brown 10 YR 7/3	L	Massive, breaking to weak prismatic, friable, moist
	C-till	20 - 36"	Pale brown 10 YR 6/3	L	Massive, friable, moist
	C-till	36 - 48"	Pale brown 10 YR 6/3	SC	Massive, sticky, wet
	C-till	48 - 60"	Pale brown 10 YR 6/3	L	Massive, slightly sticky, wet
2 - 3	Ap	0 - 6	Dark brown 10 YR 4/3	L	Weak granular, very friable, moist
	Btsa	6 - 14"	Yellowish brown 10 YR 5/4	CL	Prismatic, breaking to blocky, slight staining, friable, moist
	Ccasa	14 - 24"	Light grey 10 YR 7/2	L	Massive, breaking to weak prismatic, friable, moist

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
2 - 3 (cont.)	C-till	24 - 36"	Light grey 10 YR 7/2	L	Massive, sticky, wet
	C-till	36 - 48"	Pale brown 10 YR 6/3	L	Massive, slightly sticky, wet
2 - 4	Apsa	0 - 9"	Dark brown 10 YR 4/3	SL	Massive, friable, moist
	Ccasa	9 - 20"	Pale brown 10 YR 6/3	L	Massive, breaking to blocky, fairly friable, moist
	C-till	20 - 48"	Pale brown 10 YR 6/3	SCL	Massive, sticky, wet
	C-till	48 - 54"	Pale brown 10 YR 6/3	L	Massive, sticky, wet
3 - 1	Ap	0 - 5"	Dark brown 10 YR 4/3	SL	Massive, breaking to weak granular, friable, dry
	Bt	5 - 11"	Dark brown 10 YR 4/3	SL	Massive, breaking to prismatic, friable, moist
	Bmk	11 - 15"	Greyish brown 10 YR 5/2	SL	Prismatic, friable, moist
	Cca	15 - 27"	White 10 YR 8/1	L	Massive, breaking to prismatic, friable, moist
	C-till	27 - 34"	Very pale brown 10 YR 7/3	SL	Massive, friable, moist

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
3 - 2	Ap	0 - 4"	Dark brown 10 YR 4/3	SL	Massive, breaking to weak granular, friable, moist
	Btsa	4 - 13"	Yellowish brown 10 YR 5/4	L	Prismatic, friable to slightly sticky, moist
	BCksa	13 - 16"	Yellowish brown 10 YR 5/4	L	Massive, breaking to weak prismatic, friable to slightly sticky, moist
	Ccasa	16 - 31"	Very pale brown 10 YR 7/3	SL	Massive, breaking to prismatic, slightly sticky, wet
	Sand lens	31 - 33"	--	-	--
	C-till	31 - 42"	Light grey 10 YR 7/2	SL	Massive, friable, moist
3 - 3	Ap	0 - 5"	Dark brown 10 YR 4/3	SL	Massive, breaking to granular, friable, moist
	Bm	5 - 11"	Greyish brown 10 YR 5/2	SL	Massive, breaking to weak prismatic, friable, moist
	Ccasa	11 - 21"	Light brownish grey 10 YR 6/2	L	Massive, breaking to weak prismatic, friable, moist
	C-till	21 - 44"	Very pale brown 10 YR 7/3	SL	Massive, friable, moist
3 - 4	Ahsa	0 - 3"	Dark brown 10 YR 4/3	SiL	Massive, breaking to weak granular, friable, moist

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
3 - 4 (cont.)	Sand lens	3 - 7"	Yellowish brown 10 YR 5/4	S	Loose, friable, moist
	Alluvial	7 - 20"	Dark brown 10 YR 4/3	L	Massive, friable to soft, moist
	Sand lens	20 - 24"	Light brownish grey 10 YR 6/2	LS	Loose, friable, wet
	Till	24 - 40"	Pale brown 10 YR 6/3	SCL	Massive, friable, wet
4 - 1	Apsa	0 - 5"	Dark brown 10 YR 4/3	SL	Weak granular, friable, moist
	Btsa	5 - 14"	Yellowish brown 10 YR 5/4	L	Prismatic, friable, moist
	Ccasa	14 - 24"	White 10 YR 8/1	SiL	Massive, breaking to prismatic, friable, moist
	Wet sand lens	27 - 30"	--	-	--
	C-till	24 - 45"	Light grey 10 YR 7/2	L	Massive, friable, moist
4 - 2	Apsa	0 - 5"	Dark brown 10 YR 4/3	SL	Massive, breaking to weak granular, friable, moist
	Btsa	5 - 14"	Brown 10 YR 5/3	L	Massive, breaking to prismatic friable, moist

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
4 - 2 (cont.)	Ccasa	14 - 19"	White 10 YR 8/1	L	Massive, breaking to prismatic, friable, moist
	C-sand lens	19 - 35"	Light brownish grey 10 YR 6/2	SL	Massive, friable, wet
	C-till	35 - 40"	Pale brown 10 YR 6/3	L	Massive, friable to slightly sticky, moist
	C-sand lens	40 - 51"	Pale brown 10 YR 6/3	LS	Loose, friable, wet
	C-till	51 - 56"	Pale brown 10 YR 6/3	L	Massive, friable to slightly sticky, wet
4 - 3	Apsa	0 - 4"	Dark brown 10 YR 4/3	L	Granular, friable, dry
	Btsa	4 - 12"	Yellowish brown 10 YR 5/4	L	Prismatic, friable, moist
	Cca	12 - 18"	Light grey 10 YR 7/2	L	Massive, breaking to prismatic, friable to slightly sticky, moist
	Sand lens	22 - 24"	--	-	--
	C-till	18 - 32"	Very pale brown 10 YR 7/3	L	Massive, friable, moist
	C-sand lens	32 - 50"	Pale brown 10 YR 6/3	SL	Loose, friable, wet

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
4 - 4	Ap	0 - 6"	Greyish brown 10 YR 5/2	L	Massive, breaking to weak granular, friable, moist
	Bt	6 - 20"	Yellowish brown 10 YR 5/4	SiCL	Prismatic, friable, moist
	Ccasa	20 - 26"	Light grey 10 YR 7/2	SiL	Massive, breaking to weak prismatic, friable, moist
	C-till	26 - 46"	Pale brown 10 YR 6/3	L	Massive, friable, moist
1 - A	Lacustrine	9 - 10'	--	SiL	--
	Lacustrine	14 - 15'	--	SiCL	--
	Bedrock	19 - 20'	--	SiCL	--
1 - B	Till	9 - 10'	--	L	--
	Lacustrine	14 - 15'	--	CL	--
	Lacustrine	19 - 20'	--	L	--
	Lacustrine	24 - 25'	--	L	--
	Wet sand lens	25 - 28'	--	-	--
	Bedrock	28 - 30'	--	L-CL	--

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
1 - C	Till	40 - 48"	Pale brown 10 YR 6/3	L	Massive, fairly friable, moist
	Saline till	7 - 8'	Light grey 10 YR 7/2	CL	Massive, slightly sticky, wet
	Bedrock	9 - 10'	Light brownish grey 10 YR 6/2	CL	Blocky, fairly firm, moist
2 - A	Till	9 - 10'	--	L	--
	Till	14 - 15'	--	L	--
	Bedrock	17 - 18'	--	CL	Very hard, dry
2 - B	Till	8 - 10'	--	SiL	Friable
	Till	10 - 11'	--	L	Fiable
	Till	14 - 15'	--	SCL L	--
	Bedrock	17 - 19'	--	CL	--
2 - C	Lacustrine	9 - 10'	--	L	Moist
	Lacustrine	14 - 15'	--	L	Moist
	Till	19 - 20'	--	SCL	--
	Till	24 - 25'	--	L	Moist
	Bedrock	29 - 30'	--	L	--

* Munsell colors

1 N.S.S.C.C. 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
3 - B	Till	9 - 10'	--	L	--
	Till	14 - 15'	--	SL	--
	Wet sand lens	15 - 17'	--	-	--
	Till	19 - 20'	--	L	--
	Till	24 - 25'	--	L	--
	Bedrock	44 - 45'	--	SiC C	Hard, dry
4 - A	Till	9 - 10'	--	L	Moist
	Till	14 - 15'	--	L	Moist
	Till	19 - 20'	--	L	--
	Sand lens	20 - 25'	--	SL	Wet
	Till	29 - 30'	--	CL	Very dense and compact
	Bedrock	33 - 34'	-	SiCL	--
5 - 1	Ah	0 - 8"	--	L-SL	--
	Till	4 - 5'	--	L	--
	Bedrock	10 - 11'	--	SiC	--
	Bedrock	17 - 18'	--	SiC	Very hard

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
6 - 1	Ap	0 - 6"	--	L	--
	Bedrock	4 - 5'	--	L	--
	Bedrock	9 - 10'	--	L	--
7 - 1	Ah	0 - 10"	--	SCL	--
	Bedrock	4 - 5'	--	SL	--
	Bedrock	8 - 10'	--	SCL	--
	Bedrock	14 - 15'	--	SCL	Hard, dry
7 - 2	Ap	0 - 4"	--	L	--
	Till	4 - 5'	--	L	--
	Till	14 - 15'	--	SL	--
	Sandy till	27 - 28'	--	LS	--
	Till	29 - 30'	--	SL	Moist
	Till	39 - 40'	--	L	--
	Till	44 - 45'	--	L	--
	Sand	53 - 55'	--	SL	Wet

* Munsell colors

1 N.S.S.C.C., 1963

Table 1. Profile Descriptions

Site No. - Profile No.	Horizon	Depth	Color* Dry	Texture	Structure and Consistency[1]
8 - 1	Ah	0 - 8"	--	SL	--
	Till	3 - 3½'	--	L	--
	Till	8 - 10'	--	L	--
	Till	14 - 15'	--	L	--
	Till	19 - 20'	--	L	--
	Till	29 - 30'	--	L	--
	Till	39 - 40'	--	L	--
	Till	44 - 45'	--	L	--
	Bedrock	55 - 58'	--	CL-C	--

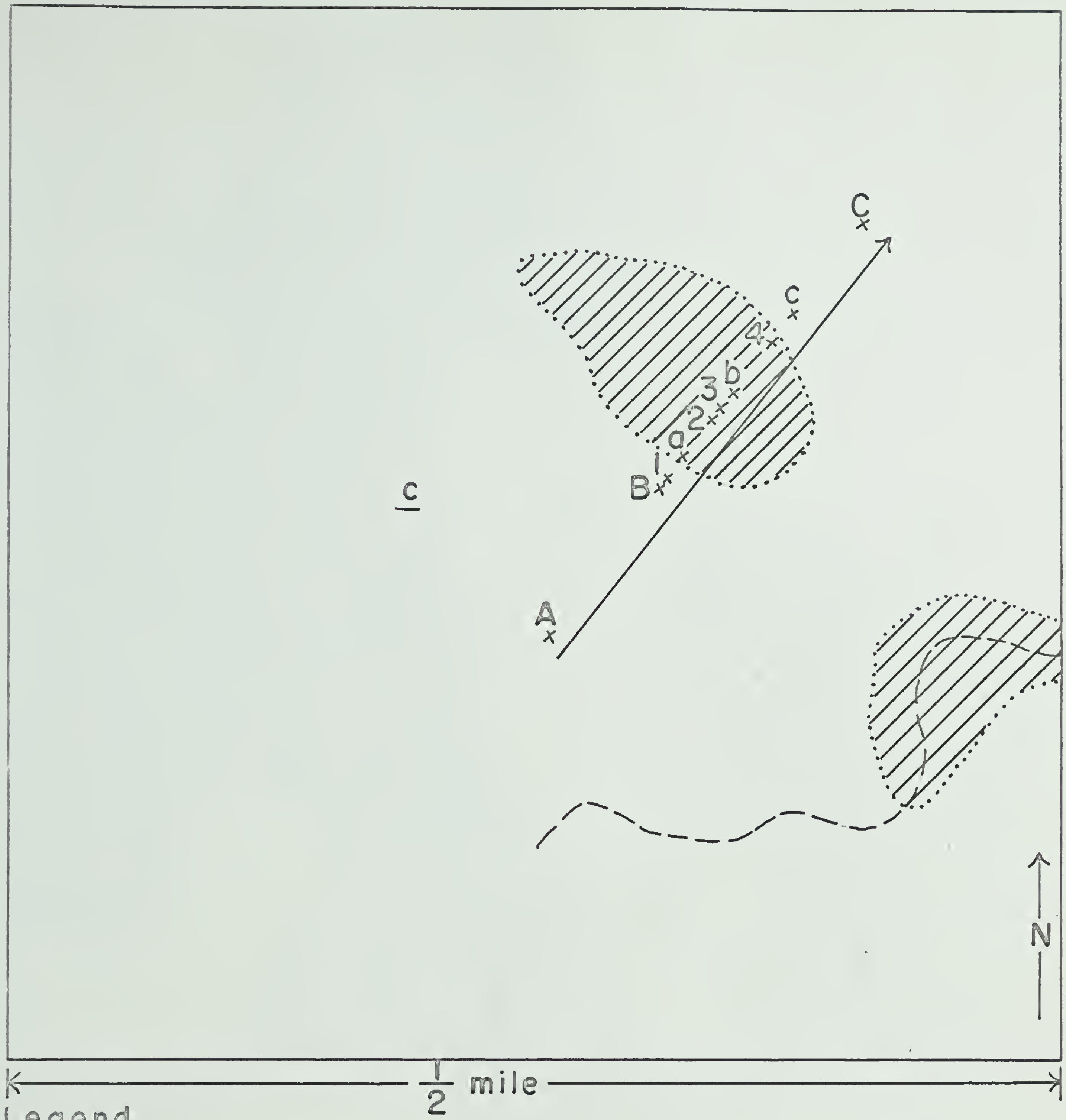
* Munsell colors

1 N.S.S.C.C., 1963

Legend

	direction of slope	1 to 6	locations of profiles sampled
	topography line	a to c	locations of wells
c	2 - 5% slope	A and B	locations of deep drill samples
d	6 - 9% slope		
	slough		
	boundary of saline areas		
	saline areas		
	drainage course		

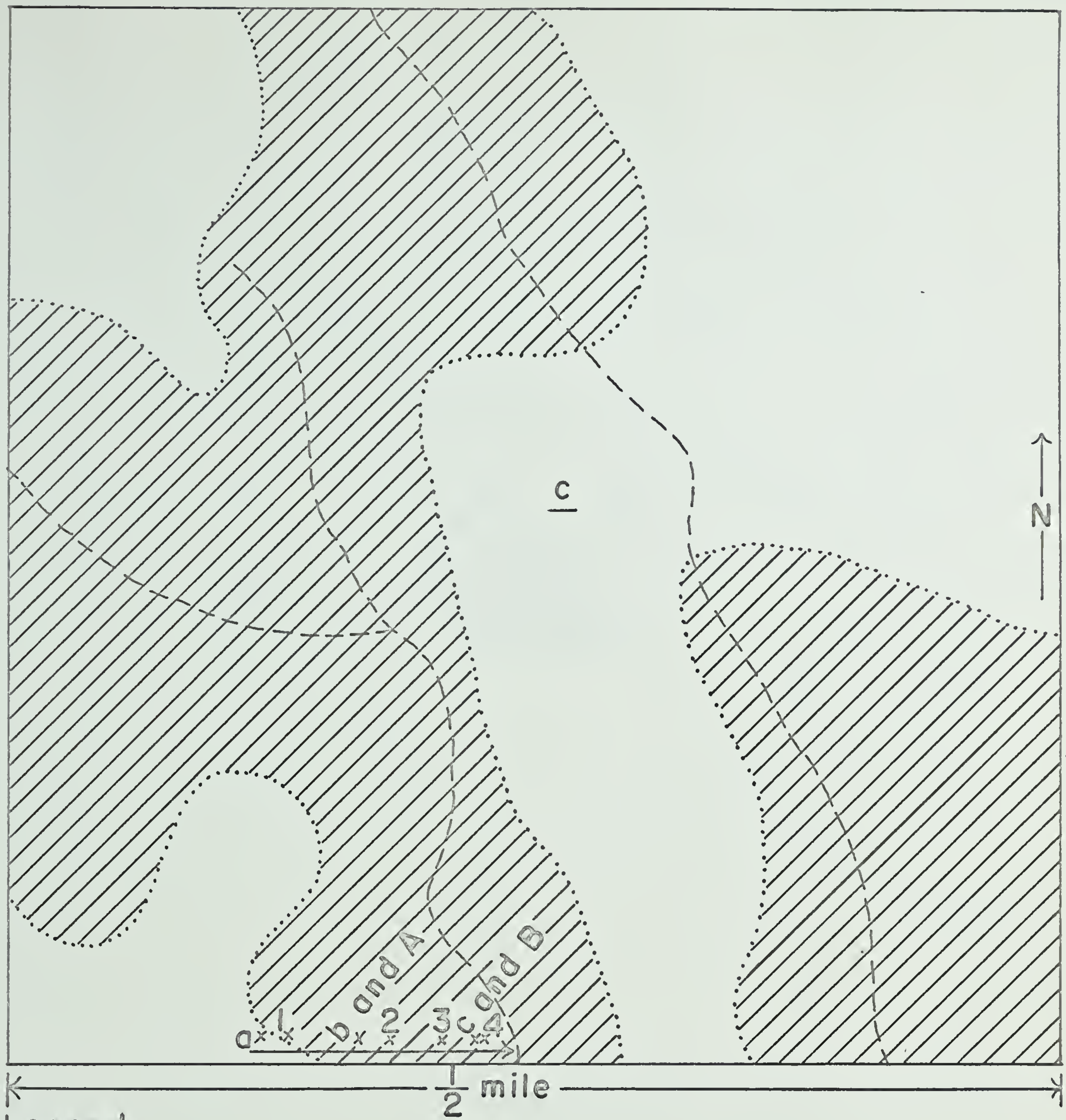
Figure 2a. Plan view of site 1, showing locations of sampling sites and wells.



Legend

⟶	direction of slope
c	2 - 5% slope
....	boundary of saline area
//////	saline area
	drainage course
1 to 4	locations of profiles sampled
a to c	locations of wells
A to C	locations of deep drill samples

Figure 2b. Plan view of site 2, showing locations of sampling sites and wells.



Legend

⟶	direction of slope
c	2 - 5% slope
....	boundary of saline areas
////	saline areas
- - -	drainage courses
1 to 4	locations of profiles sampled
a to c	locations of wells
A and B	locations of deep drill samples

Figure 2c. Plan view of site 3, showing locations of sampling sites and wells.

Legend

	direction of slope	1 to 4	location of soil profiles sampled
	topography line	a to c	locations of wells
c	2 - 5% slope	A	location of deep drill sample
d	6 - 9% slope		
	slough		
	boundary of saline area		
	saline area		
	drainage course		

Figure 2d. Plan view of site 4, showing locations of sampling sites and wells.

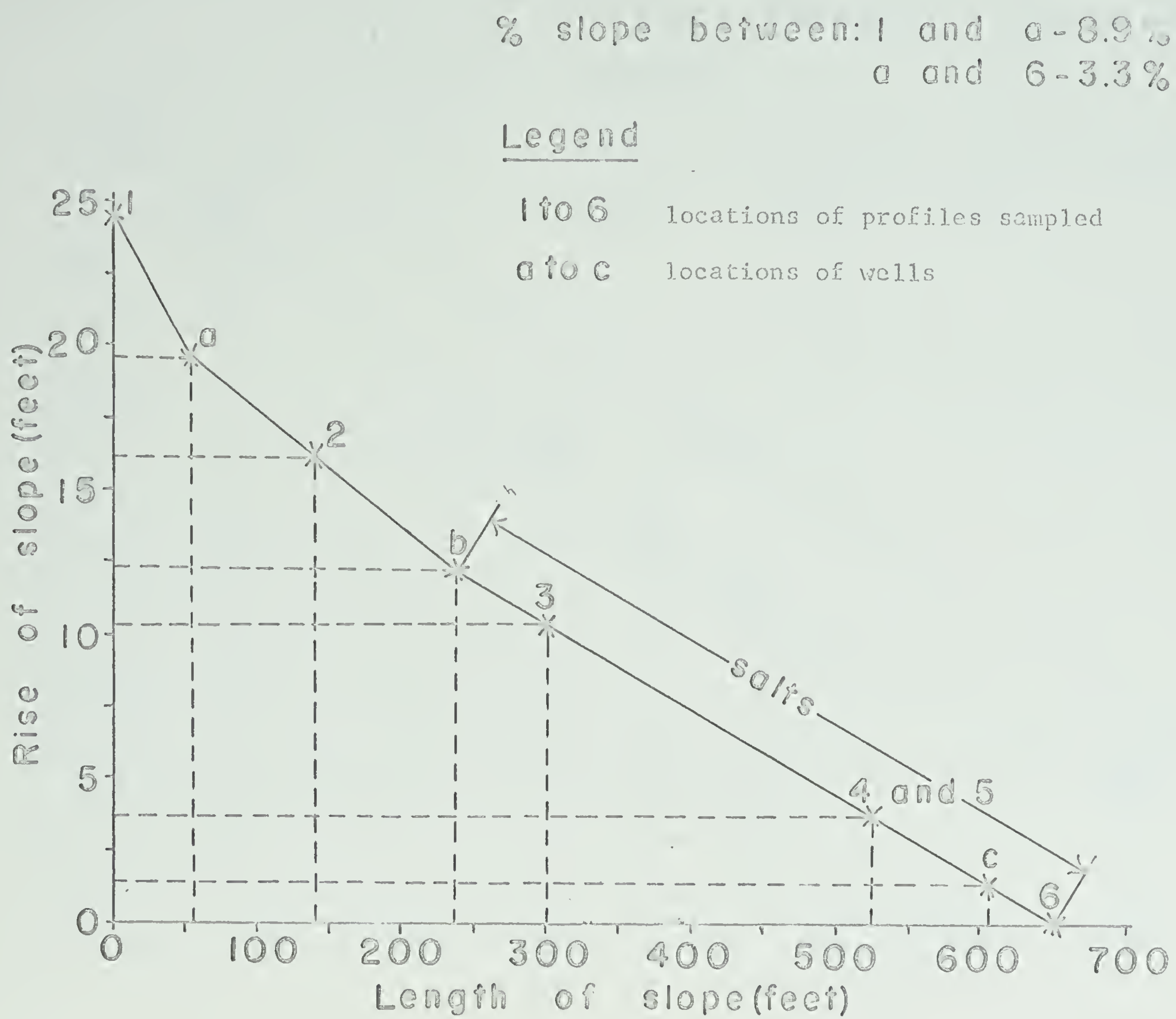


Figure 3a. Schematic drawing of site 1, showing locations of soil profiles sampled, and wells, in relation to topography

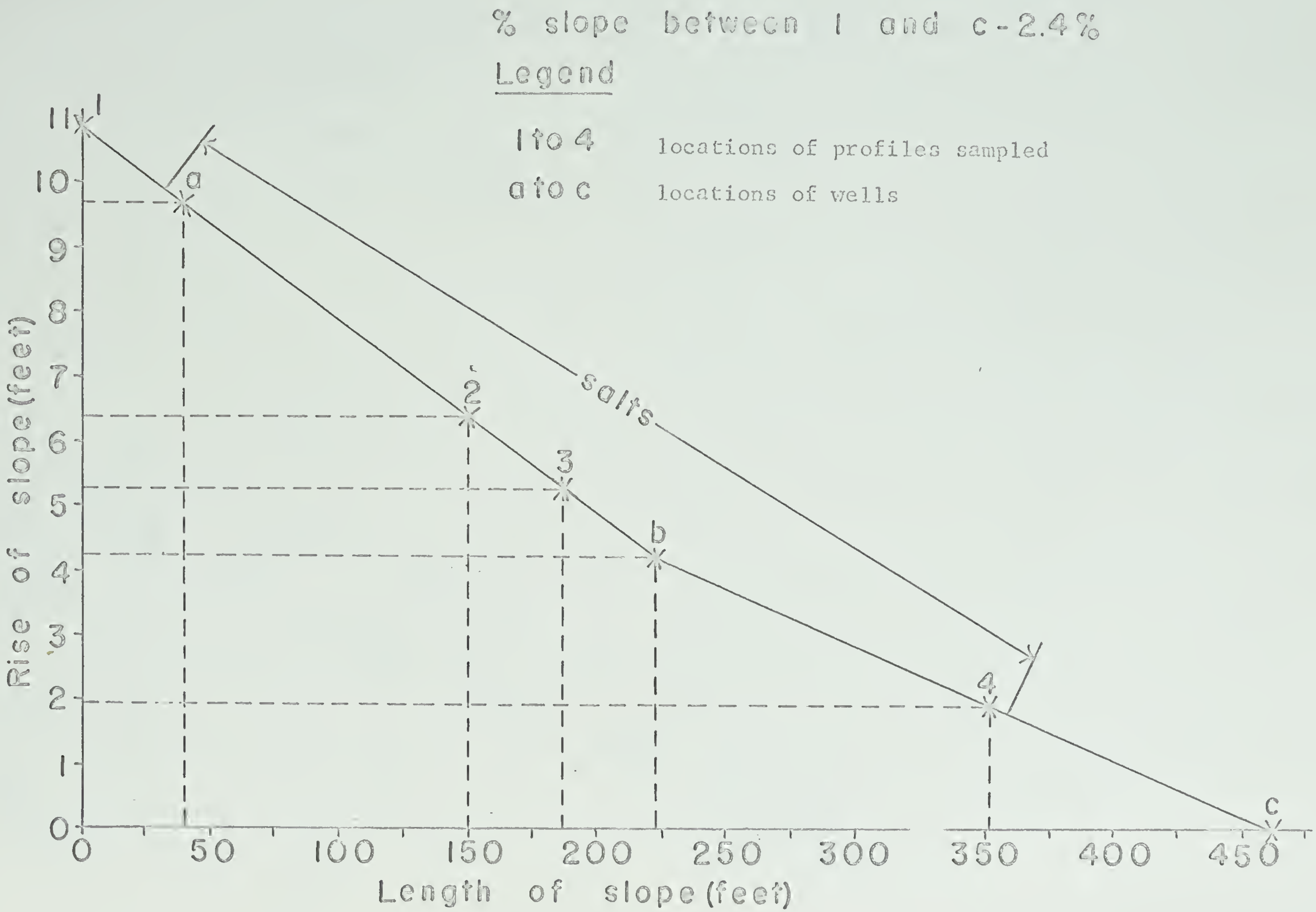


Figure 3b. Schematic drawing of site 2, showing locations of soil profiles sampled, and wells, in relation to topography

% slope between a and 4 - 2.3 %

Legend

1 to 4 locations of profiles sampled

a to c locations of wells

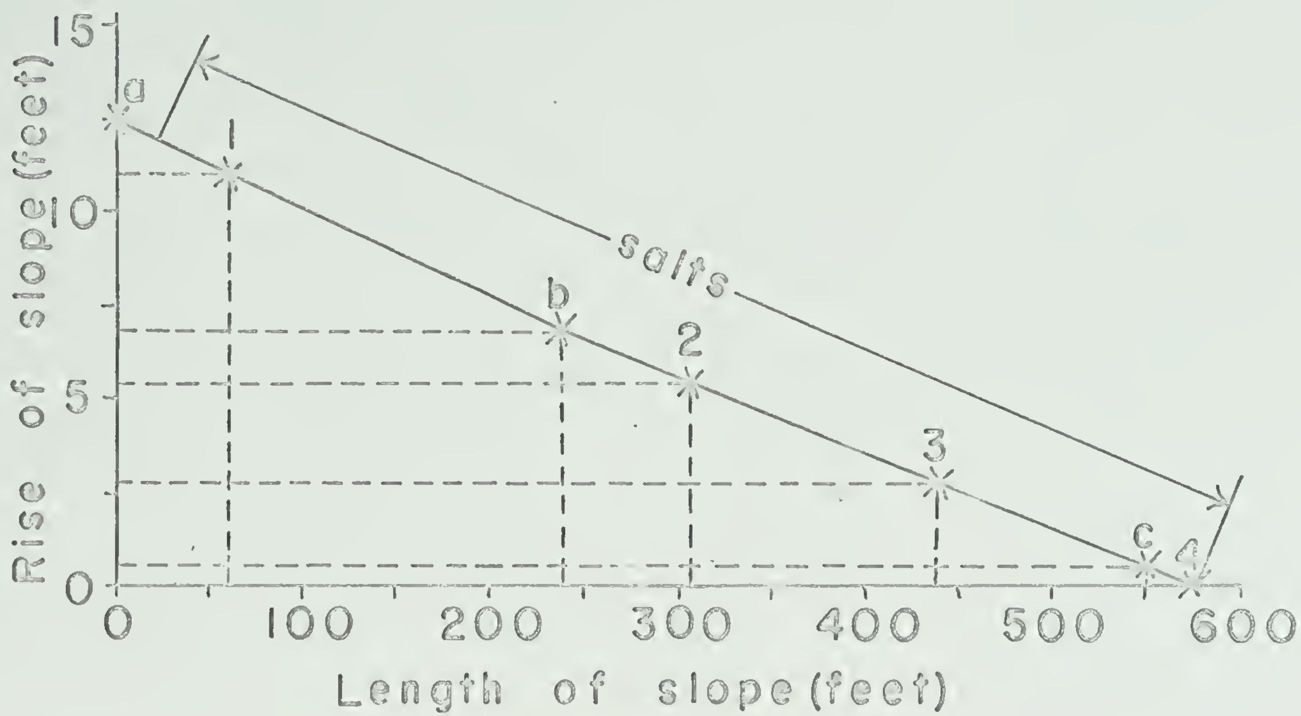


Figure 3c. Schematic drawing of site 3, showing locations of soil profiles sampled, and wells, in relation to topography

% slope between: 1 and c - 1.7 %
c and 4 - 1.1 %

Legend

1 to 4 locations of profiles sampled

a to c locations of wells

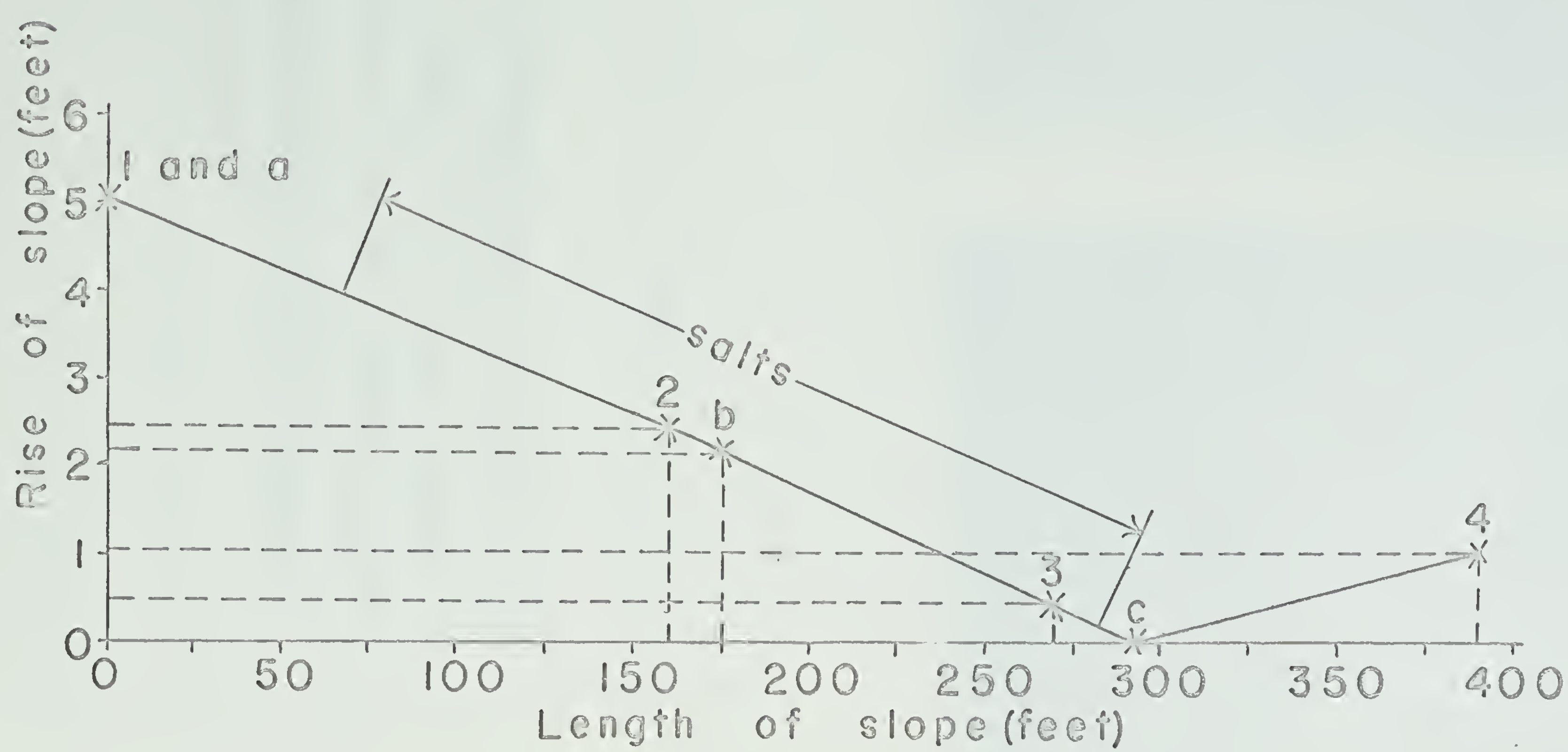


Figure 3d. Schematic drawing of site 4, showing locations of soil profiles sampled, and wells, in relation to topography

Site 2 Site 4

Plate 2. Photos of two sampling sites. Note white salts on the soil surface, and the sparse vegetation, comprised mostly of the previous year's growth of Salsola kali (Russian thistle) (pictures taken in early spring).

At site 4, part of the field was in summerfallow, and part was seeded to barley, at the time of sampling. Profiles 1, 2, and 3 were sampled on a southeast-facing slope, and profile 4 was sampled on a northwest-facing slope. Profile 1 was sampled in the summerfallow portion of the field, where no salts were evident on the surface. Profiles 2, 3, and 4 were sampled where barley had been seeded. There was no barley growth, and salt crusts were evident on the surface at the location of profile 2. Salts were also evident on the surface where profile 3 was sampled, and there was poor growth of barley. In the area where profile 4 was sampled, there was good barley growth, and no salts were evident on the surface. A 3-inch sand lens was observed at the 27-inch depth in profile 1, 16-inch and 11-inch sand lenses were observed at the 19-inch and 40-inch depths respectively in profile 2, and a 2-inch sand lens was observed at the 22-inch depth in profile 3.

Descriptions of deep drill sampling sites 5 to 8 follow:

Site 5: N.E. 30-16-24-W.4. The hole was drilled in a location of high elevation in the study area, between 3400-foot and 3500-foot contours, near the edge of a slough.

Site 6: S.W. 26-16-25-W.4. This hole was drilled on a hill top, one of the highest elevations in the study area, near a 3500-foot contour.

Site 7: S.W. 25-16-24-W.4. Hole 1 was drilled on a sandstone bedrock high, near a 3500-foot contour (The Thigh Hills). Hole 2 was drilled about two thirds of a mile northeast of hole 1, and between 3400-foot and 3500-foot contours.

Site 8: S.W. 36-16-24-W.4. This hole was drilled in an area of "c" topography (2 - 5%), north of the sandstone bedrock-high, and near a 3300-foot contour.

Soil profiles were sampled by horizons, and deep drill holes were sampled according to depth and variation in parent geologic materials encountered during drilling.

Methods

A. Aerial Photograph Study

Saline areas were outlined on aerial photographs, with the aid of a pocket stereoscope. Outlines of the saline areas were transferred from the photographs, to maps having a scale of 1 inch to the mile. Outlines of the saline areas were then transferred from these maps, to a map having a scale of 1 inch to 2 miles. The surficial glacial deposits of the study area were outlined from Alberta Soil Survey field township maps, and are also shown on map 1. Maps of the surface and bedrock contours (maps 3 and 4) of a portion of the study area are also included. These maps were originally prepared by K.W. Geiger (1965) and copies were included with his permission.

B. Water Table and Ground Water Movement Studies

Shallow wells (10 to 15 feet deep) were drilled at three locations, at each of the four soil sampling sites in the study area. These wells consisted of 4-inch diameter galvanized pipe, placed in holes drilled with a Sterling drill mounted on the back of a truck.

Sodium fluorescein was placed in the well at the top of the slope at each of the four soil sampling sites. Water samples were collected from wells at all sites in order to determine whether or not the dye had moved down slope with the ground water. Water table samples were also collected for soluble salt analysis.

Water samples were collected from the wells, by lowering a small drinking glass on a piece of twine down the wells.

Observations of water table depths were recorded in the wells during April to November of 1965, by R.A. Milne of the Lethbridge Research Station.

C. Preparation of the Sample

The soil samples were collected and allowed to air dry at room temperature. They were ground to pass through a 2-mm. sieve, and were stored in non-sealing screw top containers.

D. Physical Analysis

Mechanical analysis of the soil and parent geologic material samples was determined by the pipette method described by Toogood and Peters (1953).

The percentage of fine clay is based on total clay, while the percentages of sand, silt, and clay are based on the oven dry weight of organic matter, carbonate, and soluble, salt-free soil material.

E. Chemical Analyses

(a) Soil reaction: pH was determined on a saturated soil paste as outlined by Doughty (1941), using a Beckman Zeromatic pH meter equipped with a glass and calomel electrode.

(b) Electrical conductivity of saturation extracts: A saturated soil paste was prepared according to the procedure outlined in U.S.D.A. Handbook 60 (1954). The saturation extract was obtained by suction, and the conductivity of the extract was measured with a direct reading Solu-Bridge Model RD-26.

(c) Soluble salts: Sodium and potassium were determined with a Beckman Model DU flame spectrophotometer. The wavelengths used were 589 mu for sodium, and 769 mu for potassium. Calcium and magnesium were determined by compleximetric titrations with Ethylenediaminetetraacetate (E.D.T.A.) as described by Cheng and Bray (1951) and outlined in Handbook 60.

Bicarbonates were determined with the use of a radiometer titrator type TTAlb equipped with a glass and calomel electrode. The solution was titrated with 0.01 N HCl to pH 4.4. The $CO_3^=$ was considered to be absent if the pH of the solution was less than 9.0 (Handbook 60). Chlorides were measured with the radiometer titrator, using a silver and mercurous sulfate calomel electrode to determine the end point. Prior to titration, roughly 25 ml. of 50 percent acetic acid were added to each sample solution in order to facilitate the coagulation of fine particles in the precipitate. The solution was titrated with 0.001N $AgNO_3$ solution until the potential of the solution was equal to a blank. Sulfates were determined by the turbidimetric method, where sulfate is precipitated with $BaCl_2$ crystals. A Beckman model B spectrophotometer was used for the determination, at a wavelength of 490 mu.

(d) Exchangeable cations and exchange capacity: Exchangeable cations were extracted from the samples with normal ammonium acetate adjusted to pH 7, as outlined in A.O.A.C., methods of analysis (1955). Exchangeable sodium and potassium were determined with the model DU Beckman flame spectrophotometer. Exchangeable calcium and magnesium were determined by the E.D.T.A. method of Cheng and Bray (1951), as outlined in Handbook 60.

IV. RESULTS AND DISCUSSION

Salt Maps from Photographs taken in Different Years

From studying the maps (maps 1 and 2), drawn from photographs taken in different years, it appears that the extent of salinity has increased substantially with time. Many saline areas have increased in size and numerous small areas have joined to form larger areas. The greatest increase in the extent of salinity is in township 17, range 23. The photographs used for township 17, range 23, were taken 13 years apart, while the photographs used for the rest of the area were taken 4 and 5 years apart. Other factors besides the date of photography may have influenced the appearance of salts on the photos. For instance, the salts would not be as evident when the soil was at a high moisture content as when the soil was relatively dry. Another factor that might mask the appearance of the salts is the amount of spectroreflectance on the day of photography.

Relation of Salts to Parent Material, Soils, and Drainage

Glacial till is the surficial deposit throughout most of the study area although a mantle (usually $<$ 3 feet thick) of medium-textured lacustrine deposits overlies the till in some instances. The salts seem to be randomly distributed throughout the area, in relation to these deposits. The extent of salinity is almost nil in the area of alluvial aeolian deposits in the southeast corner of the study area. Heavy concentrations of salts appear on the surface wherever solonetzic soils are present.

In the southeastern two-thirds of the study area, the pattern of salts parallels the direction of drainage. A definite northwest-southeast alignment is evident. This pattern is not evident in the northern

third of the study area. There is a northeast-southwest alignment of the salt pattern in township 18, range 27, associated with till ridges which are oriented in the same direction.

Relation of Salts to Bedrock and Surface Contours

In the area where bedrock contours were outlined (map 4), there is a general slope of the bedrock surface from west to east. The highest bedrock elevation is the 3500-foot contour in the Porcupine hills on the west side of the study area, and on a bedrock high in township 16, range 25. The lowest bedrock elevation is the 2800-foot contour near the southeast corner of the study area.

The 3200-foot bedrock contour appears to be the boundary of a large bedrock valley. It begins in township 17, range 26, and follows the Little Bow River valley southeast, until it widens out in township 15, range 26. The 3200-foot contour extends southeast to township 12, range 25, and east to township 16, range 23. There appears to be a high concentration of surface salts associated with this valley, bounded roughly on the west by the 3200-foot contour, and on the east by the Little Bow River, south to the middle of township 14, range 25. The area of alluvial aeolian deposits begins here, and is the eastern boundary of the heavy salt concentration south to township 12, range 25.

The 3200-foot bedrock contour appears to bound smaller bedrock valleys in township 16, range 24; township 16, range 23; and township 17, range 23. High surface salt concentrations occur in these areas. High concentrations of surface salts in township 17, ranges 25 and 26 also appear to be associated with the 3200-foot bedrock contour.

A bedrock high, indicated by a 3500-foot contour, occurs in township 16, range 25, to the east of which lies a concentration of surface

salts. Also, a bedrock high, indicated by a 3400-foot contour, occurs in township 18, range 23. There is a concentration of surface salts immediately northeast of this location.

Bedrock is very near the surface throughout most of the area, for which surface and bedrock contours were drawn (maps 3 and 4). Generally a correlation appears evident between surface salt concentrations and shallow depths to bedrock, except where bedrock valleys are located. There is an increased thickness of surficial deposits in these valleys, yet heavy concentrations of surface salts occur. There is a marked absence of surface salts in township 15, range 25, where an increased thickness of surficial deposits occurs. East of this location, where bedrock is again near the surface, heavy concentrations of surface salts occur.

In the area of alluvial-aeolian deposits in the southeast corner of the study area, very few surface salts are evident. The depth to bedrock is greater here, as indicated by comparing the surface and bedrock contours. Immediately southeast of the alluvial-aeolian area, in townships 12 and 13, range 23, where bedrock is again near the surface, increased surface salt concentrations are evident.

Water Table Studies

Table 2. Fluorescent Dye in Water Samples from Wells (1965).

Site No.-Well No.	May 7	July 5
* 1 - 1	not sampled	distinctly green
2	pale green	pale green
3	clear	pale green
2 - 1	not sampled	distinctly green
2	frozen	clear
3	clear	pale green
3 - 1	not sampled	distinctly green
2	pale green	pale green
3	clear	clear
4 - 1	not sampled	distinctly green
2	pale green	clear
3	frozen	clear

* Water in the slough at the bottom of the slope was pale green, while water in a dugout two-tenths of a mile south was clear.

Ground Water Movement

Dye was placed in well 1 at each of the four soil sampling sites on Oct. 20, 1964. In the spring and early summer of 1965, water samples were collected from the wells and checked for color, to determine whether the groundwater was moving down slope. Color in the water samples is reported in table 2.

These results indicate that ground water seems to move down slope at all four sites.

At site 2, there may have been a different source of ground water for well 2 than for well 3, since the water was clear in well 2 and colored in well 3. Different sources of ground water in these wells could be caused by local ground water flow systems, flowing from different directions.

The results at site 4 suggest that the rate of local ground water movement at different positions on the slope may vary with the season. The flow from well 1 toward well 2 may predominate in the spring, while the flow from well 3 toward well 2 may predominate in early summer. These flow rates may be related to the amount and intensity of spring runoff and summer precipitation.

Water Table Levels

Studies during 1965 of water table levels in the wells indicated a seasonal pattern of water table fluctuations (fig. 4). Water tables seem to be lowest in May, then rise to their maximum levels in late June or early July. The levels fall slightly and become constant for the rest of the summer, then rise again slightly in late September or early October. In late fall the levels drop continuously and were last measured in late November. Water table levels were not measured during the period from December to April.

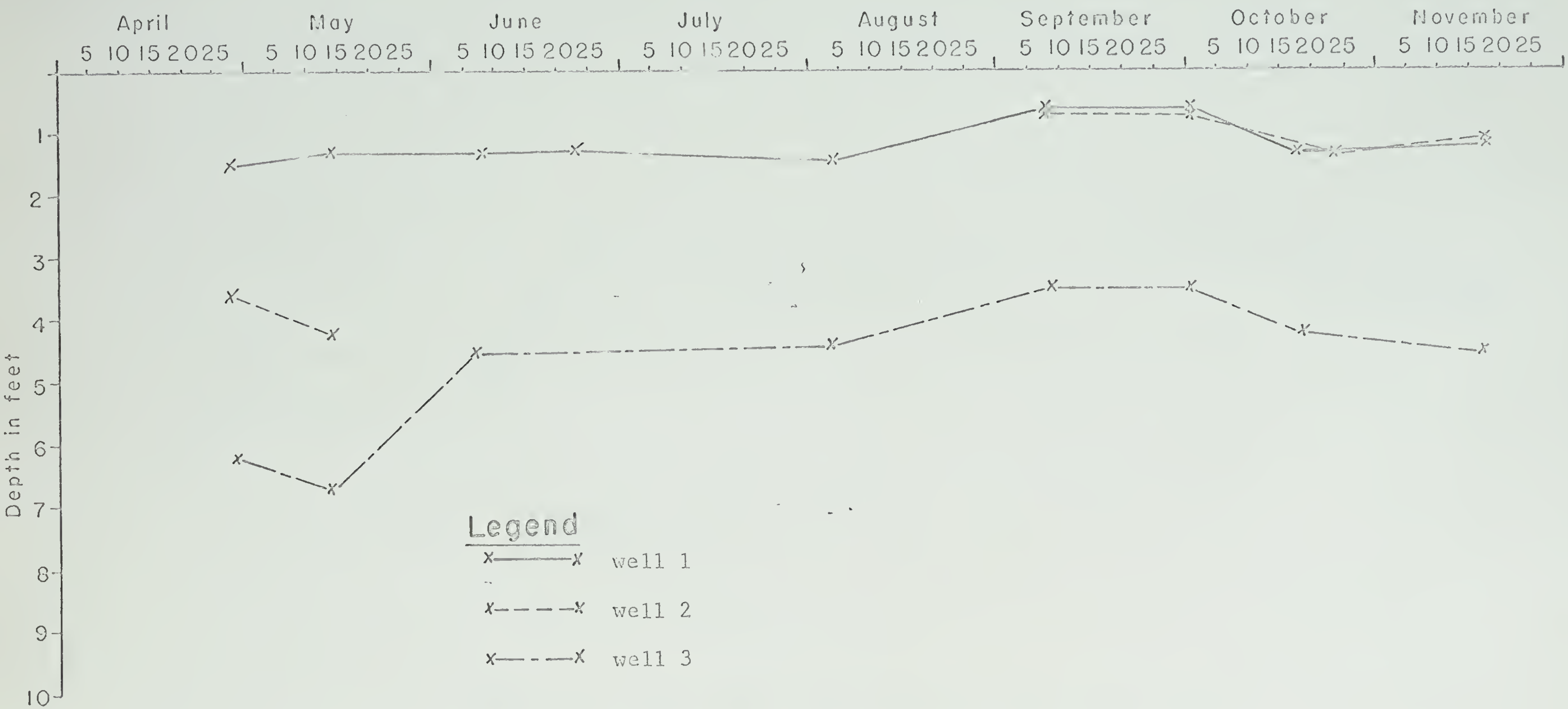


Figure 4a - monthly water table levels during 1965 at site 1

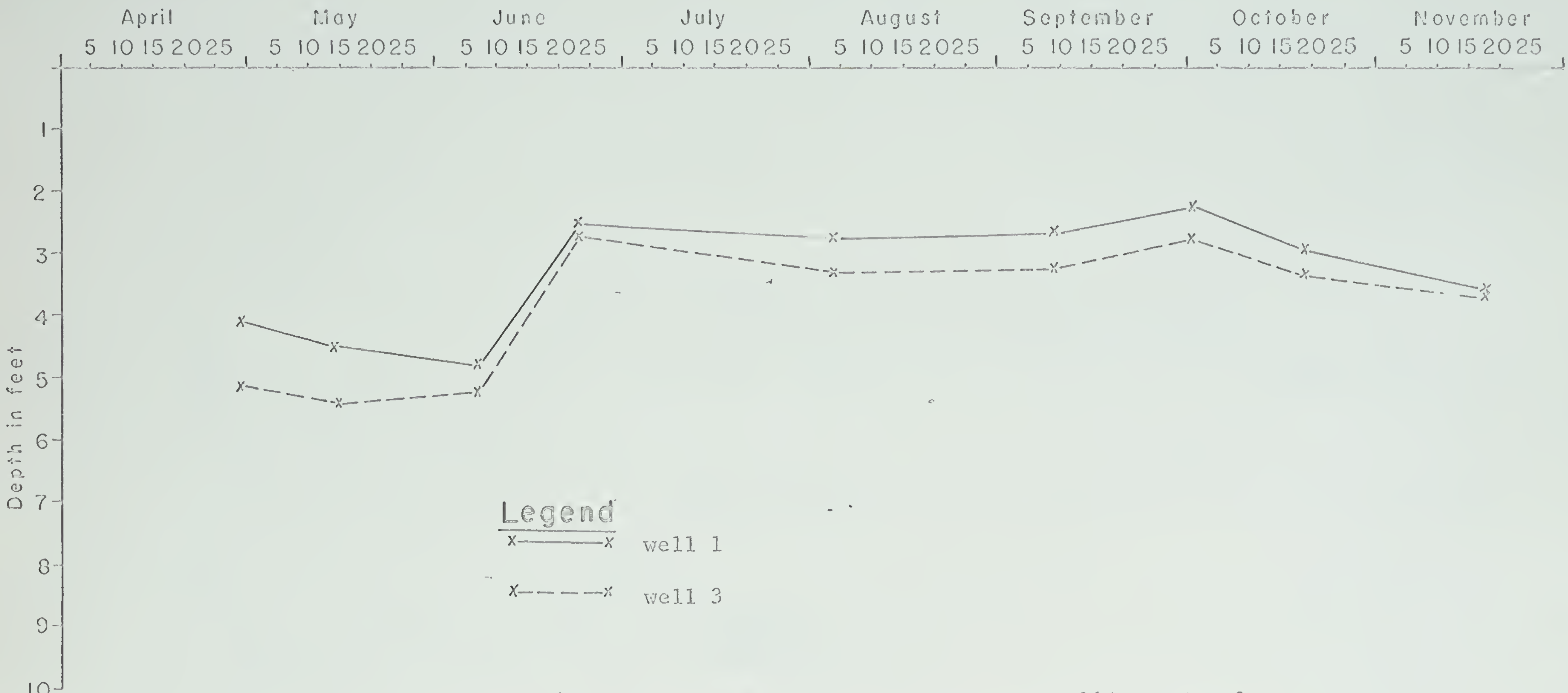


Figure 4b - monthly water table levels during 1965 at site 2

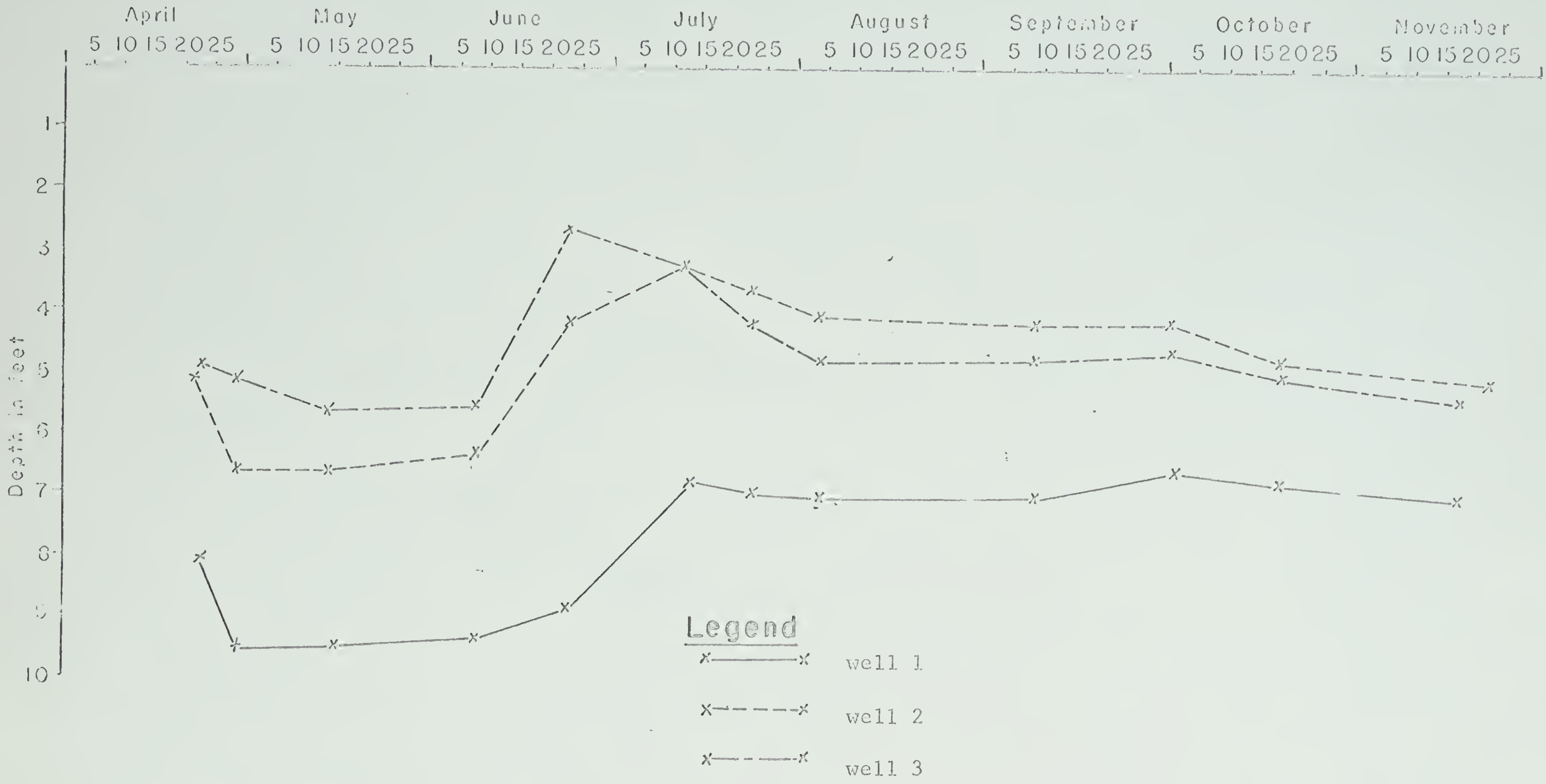


Figure 4c - monthly water table levels during 1965 at site 3

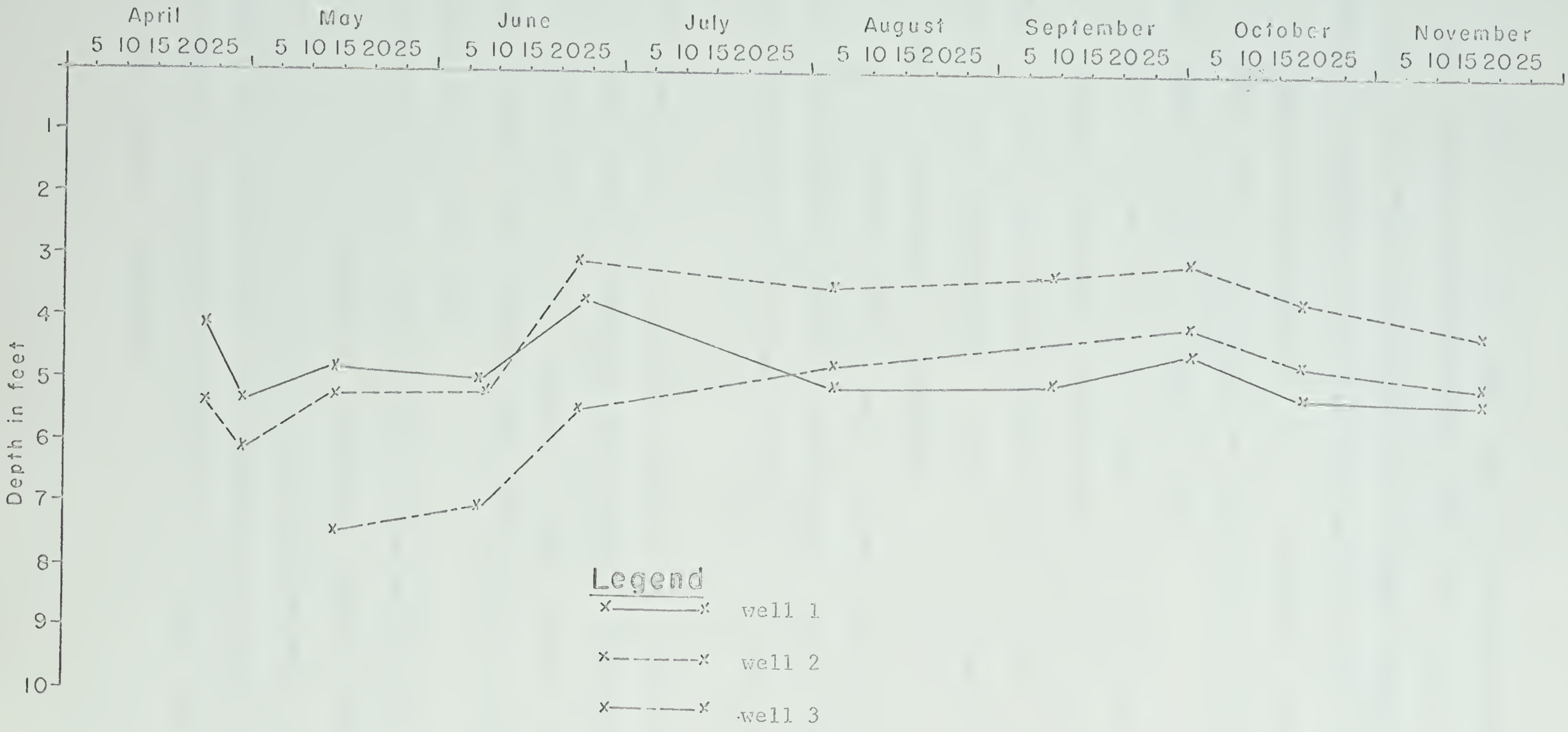


Figure 4d - monthly water table levels during 1965 at site 4.

Fluctuations of the water table levels correlated well with precipitation fluctuations in the Vulcan region during 1965 (fig. 5). The precipitation was lowest during winter, and increased slightly in May. The maximum precipitation for one month was received in June, and very little precipitation was received in July. The amount of precipitation received rose gradually during August and September, then decreased gradually during the period of October to April.

At site 1, the water table was within 1 to 2 feet of the surface in well 1 throughout the period of measurement, and was highest in September. It was 4 feet from the surface in well 2 in May, and was near the soil surface in September. In well 3, it fluctuated between 3 and 6 feet, and was highest in September.

At site 2, the water level in well 1 varied between 2 and 5 feet from the surface, and was highest in early October. It fluctuated between 2 and 5 feet at well 3, and was highest in late June and early October.

The water level at site 3 varied between 6 and 9 feet from the surface in well 1 and was highest in early October. It fluctuated between 3 and 7 feet in well 2, reaching its highest level in July, and fluctuated between 2 and 6 feet from the surface in well 3, reaching its highest level in late June.

At site 4, the water level in well 1 varied between 3 and 5 feet from the surface and was highest in late June. In well 2 it fluctuated between 3 and 6 feet, and was highest in late June and early October. The water level varied between 4 and 7 feet from the surface in well 3. It was lowest in mid-May and rose steadily to its maximum level in early October, after which it fell again.

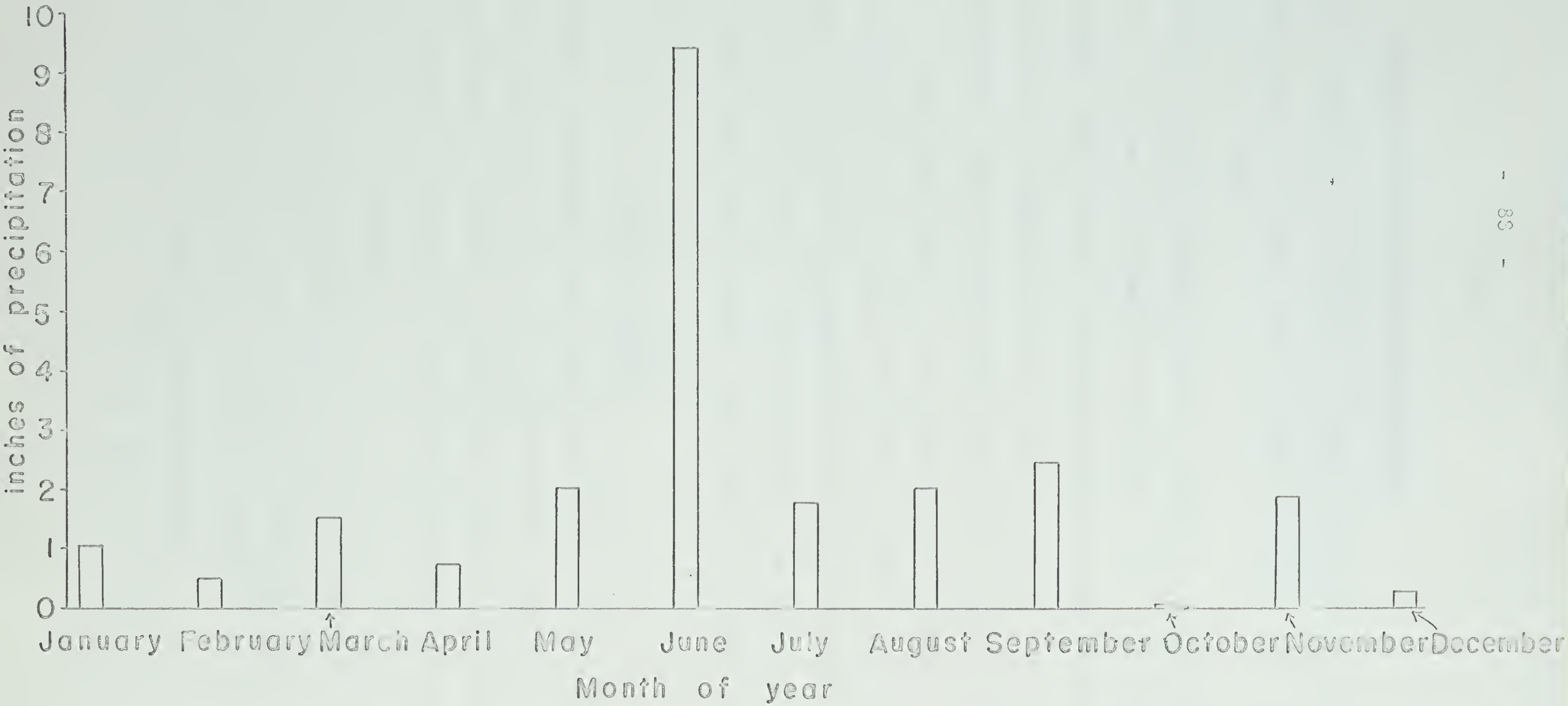


Figure 5. Inches of precipitation during 1965 at Vulcan

Soluble Salt Analysis of Water Samples

Soluble salt analysis was determined to compare and correlate salt content in ground water with that of soil and parent material. The results are reported in table 3.

The ground water samples were very saline. In general, sodium was the predominant cation and sulfate was the predominant anion, indicating that bedrock is the main source of salts. The cation that occurred in the second highest concentrations was magnesium, while calcium occurred in the third highest concentrations. Thus, it would appear that till also is a source of the salts. At site 4, the magnesium and calcium concentrations were much higher in comparison to the sodium concentration, than at the other sites. In sample 8 at this site the magnesium concentration actually exceeded the sodium concentration. These data suggest that till is the main source of the salts at this location. Small amounts of bicarbonate and very small amounts of chloride occurred.

Physical Analysis

Mechanical Analysis: Mechanical analysis was determined to help characterize the soil profiles, and to give some indication of the capacity of parent geologic material to permit or prevent water percolation and seepage. Data from mechanical analysis were also used to indicate the presence of Bt horizons in the soils studied.

A Bt horizon, as defined by the National Soil Survey Committee of Canada at the 1965 fall meeting, must meet the following requirements:

(1) If the eluviated horizon has less than 14 per cent clay, the B horizon must have 3 per cent more clay than the eluviated horizon.

Table 3. Soluble salt analysis of ground water samples

Sample No.	Conductivity mmhos./cm.	Total anions or cations from EC-me./1.	Soluble cations and anions - me./1.								
			Na^+	K^+	Ca^{++}	Mg^{++}	Total Cations	Cl^-	$SO_4^=$	HCO_3^-	Total Anions
1	8.1	81	79.9	0.5	2.3	14.0	96.7	0.6	54.1	8.0	62.7
2	20 +	300	376	1.1	12.0	108	497	1.3	287	7.1	295
3	7.1	71	58.2	0.7	13.4	15.3	87.6	1.7	50.1	3.0	54.8
4	6.2	62	63.9	0.2	2.6	13.0	79.7	1.7	46.9	6.2	54.8
5	7.5	75	67.6	0.6	17.5	13.9	99.6	1.6	59.9	2.2	63.7
6	12.3	123	128	0.4	13.5	25.1	167	2.4	104	3.1	109
7	5.0	50	27.4	0.5	18.2	24.3	70.4	2.7	34.3	2.4	39.4
8	6.8	68	34.0	0.3	10.9	59.2	104.4	1.1	57.4	4.8	63.3

Description of samples:

Sample 1. location B, site 1 - water table in very coarse soft sand at 25 feet.

Sample 2. well b, site 1.

Sample 3. location B, site 2 - water table at 16 feet.

Sample 4. well a, site 2

Sample 5. location B, site 3 - water table in sand lens at 15 feet.

Sample 6. well c, site 3.

Sample 7. location A, site 4 - water table in soft sand at 20 feet.

Sample 8. well b, site 4.

(2) If the eluviated horizon has between 15 and 40 percent clay, the ratio of the percent clay in the B horizon to the percent clay in the eluviated horizon must be "1.2" or more.

(3) If the eluviated horizon has more than 40 percent clay, the B horizon must have 8 percent more clay than the eluviated horizon.

Furthermore, the Bt horizon must be at least one-tenth the thickness of all overlying horizons. If peds are present, they must show clay skins on some or both of the vertical and horizontal ped surfaces and in the finer pores.

Mechanical analysis results are reported in table 4.

In general, the soils at site 1 were medium-textured loams (fig. 6a). Sandy loam texture occurred in the C horizons of profiles 1 and 3. Near the bottom of the slope, profile 4 had sandy loam A and B horizons, while profile 5 had sandy loam A, B, and C horizons, indicating that surface textures become sandier down slope. The Ccag horizon of profile 6 in the depression at the bottom of the slope was developed in a sand lens, and was underlain by a clay loam lacustrine substratum. The B horizons of profiles 1, 2, and 3 on the upper slope meet the percentage clay requirement for Bt horizons. In deep drill hole A, the parent material became finer in texture with depth, varying from silt loam at 10 feet to silty clay loam bedrock at 20 feet. In deep drill hole B, the glacial drift deposits were loam, while the underlying bedrock was slightly finer in texture. A 3-foot water-saturated sand lens overlaid the bedrock. The bedrock was 30 feet below the surface in deep drill hole B, indicating that the slope of the bedrock surface was steeper than the slope of the land surface.

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	S	Si	C	Fine C
					%		
1 - 1	Ah	0 - 2½"	L	48	34	18	tr*
	Bt	2½ - 10"	L	43	35	22	tr
	Cca	10 - 18"	L	30	54	16	tr
	C-till	18 - 35"	SL	55	31	14	tr
1 - 2	Ahsa	0 - 2½"	L	50	38	12	tr
	Btsa	2½ - 10½"	L	40	35	25	tr
	BC	10½ - 16½"	SiL	26	52	22	tr
	Cca	16½ - 26½"	SiL	22	60	18	tr
	C-till	26½ - 34"	L	35	44	21	tr
1 - 3	Ahksa	0 - 8"	L	47	39	14	tr
	Btksa	8 - 13"	L	45	32	23	tr
	BCksa	13 - 18"	L	30	46	24	tr
	Ccasa	18 - 24"	L-CL	26	47	27	tr
	C-till	24 - 36"	L	38	42	20	tr
	C-till	36 - 38"	SL	58	25	17	tr
1 - 4	Ahksa	0 - 4½"	SL	54	32	14	tr
	Bmksa	4½ - 9½"	SL	57	27	16	tr
	Ccasa	9½ - 15"	L	51	27	22	tr
	C-till	15 - 38"	L	41	36	23	tr
1 - 5	Ahksa	0 - 7"	SL	57	28	15	tr
	Bmksa	7 - 13"	SL	58	26	16	tr
	Ccasa	13 - 26"	SL	60	27	13	tr
	C-till	26 - 40"	L-CL	40	33	27	tr

* trace

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	Mechanical Analysis S	Si	C	Fine C
				%			
1 - 6	Ahkgsa	0 - 4"	L	26	49	25	tr*
	Bgksa	4 - 10"	SiL	27	57	16	tr
	Ccagsa	10 - 20"	SL-L	52	33	15	tr
	C - lacustrine	20 - 36"	CL	36	36	28	tr
	C - lacustrine	36 - 42"	L	39	37	24	tr
2 - 1	Ap	0 - 6"	SL	54	28	18	tr
	Bt	6 - 12"	L	41	33	26	tr
	BC	12 - 14"	L	48	35	17	tr
	Cca	14 - 24"	L	45	39	16	tr
	C-till	24 - 36"	L	41	43	16	tr
	C-till	36 - 48"	L	44	37	19	tr
2 - 2	Ap	0 - 5"	L	50	33	17	tr
	Bmsa	5 - 8"	L	47	34	19	tr
	Ccasa	8 - 20"	L	45	37	18	tr
	C-till	20 - 36"	L	45	39	16	tr
	C-till	36 - 48"	SC	47	16	37	tr
	C-till	48 - 60"	L	45	39	16	tr
2 - 3	Ap	0 - 6"	L	51	34	15	0
	Btsa	6 - 14"	CL	40	32	28	tr
	Ccasa	14 - 24"	L	36	42	22	tr
	C-till	24 - 36"	L	41	40	19	tr
	C-till	36 - 48"	L	40	37	23	tr

* trace

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	S	Si	C	Fine C
			Mechanical Analysis				
				%			
2 - 4	Apsa	0 - 9"	SL	56	32	12	0
	Ccasa	9 - 20"	L	41	34	25	tr*
	C-till	20 - 48"	SCL	50	27	23	tr
	C-till	48 - 54"	L	39	41	20	tr
3 - 1	Ap	0 - 5"	SL	56	30	14	tr
	Bt	5 - 11"	SL	54	29	17	tr
	Bmk	11 - 15"	SL	54	30	16	tr
	Cca	15 - 27"	L	48	38	14	tr
	C-till	27 - 34"	SL	68	23	9	tr
3 - 2	Ap	0 - 4"	SL	54	31	15	tr
	Btsa	4 - 13"	L	48	31	21	tr
	BCksa	13 - 16"	L	42	34	24	tr
	Ccasa	16 - 31"	SL	54	34	12	tr
	C-till	31 - 42"	SL	62	28	10	tr
3 - 3	Ap	0 - 5"	SL	66	20	14	tr
	Bm	5 - 11"	SL	57	30	13	tr
	Ccasa	11 - 21"	L	50	34	16	tr
	C-till	21 - 44"	SL	68	23	9	tr

* trace

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	S	Si	C	Fine C
				%			
3 - 4	Ah	0 - 3"	SiL-SiCL	13	60	27	tr*
	sand lens	3 - 7"	S	93	4	3	tr
	alluvial	7 - 20"	L	42	37	21	tr
	sand lens	20 - 24"	LS	81	11	8	tr
	till	24 - 40"	SCL	53	27	20	tr
4 - 1	Apsa	0 - 5"	SL	56	27	17	tr
	Btsa	5 - 14"	L	44	30	26	tr
	Ccasa	14 - 24"	SiL	29	54	17	tr
	C-till	24 - 45"	L	50	33	17	tr
4 - 2	Apsa	0 - 5"	SL	53	31	16	tr
	Btsa	5 - 14"	L	47	32	21	tr
	Ccasa	14 - 19"	L	42	40	18	tr
	C-sand lens	19 - 35"	LS	86	9	5	tr
	C-till	35 - 40"	L	47	31	22	tr
	C-sand lens	40 - 51"	SL	78	15	7	tr
	C-till	51 - 56"	L	43	33	24	tr
4 - 3	Apsa	0 - 4"	L	45	37	18	tr
	Btsa	4 - 12"	L	29	46	25	tr
	Cca	12 - 18"	L	31	49	20	tr
	C-till	18 - 32"	L	44	38	18	tr
	C-sand lens	32 - 50"	SL	79	15	6	tr
4 - 4	Ap	0 - 6"	L	45	36	19	tr
	Bt	6 - 20"	SiCL	17	53	30	tr
	Ccasa	20 - 26"	SiL	22	61	17	tr
	C-till	26 - 46"	L	50	36	14	tr

Mechanical Analysis columns: Soil Class, S, Si, C, Fine C.

* trace

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	S	Si	C	Fine C
				%			
1 - A	lacustrine	9 - 10'	SiL	42	55	3	tr*
	lacustrine	14 - 15'	SiCL	19	48	33	tr
	bedrock	19-20'	SiCL	15	52	33	tr
1 - B	till	9 - 10'	L	39	40	21	tr
	lacustrine	14 - 15'	CL	35	37	28	tr
	lacustrine	19 - 20'	L	35	39	26	tr
	lacustrine	24 - 25'	L	39	36	25	tr
	bedrock	28 - 30'	L-CL	32	41	27	tr
1 - C	till	3 - 4'	L	40	40	20	tr
	saline till	7 - 8'	CL	24	48	28	tr
	bedrock	9 - 10'	CL	32	32	36	tr
2 - A	till	9 - 10'	L	43	34	23	tr
	till	14 - 15'	L	49	32	19	tr
	bedrock	17 - 18'	CL	39	32	29	tr
2 - B	till	8 - 10'	L	45	36	19	tr
	till	10 - 11'	L	49	29	22	tr
	till	14 - 15'	SCL-L	46	28	26	tr
	bedrock	17 - 19'	CL	44	26	30	tr
2 - C	lacustrine	9 - 10'	L	52	33	15	tr
	lacustrine	14 - 15'	L	42	38	20	tr
	till	19 - 20'	SCL	52	25	23	tr
	till	24 - 25'	L	41	39	20	tr
	bedrock	29 - 30'	L	38	40	22	tr

* trace

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	Mechanical Analysis S	Si	C	Fine C
				%			
3 - B	till	9 - 10'	L	42	32	26	tr*
	till	14 - 15'	SL	58	26	16	tr
	till	19 - 20'	L	39	35	26	tr
	till	24 - 25'	L	40	35	25	tr
	bedrock	44 - 45'	SIC-C	16	41	43	tr
4 - A	till	9 - 10'	L	48	33	19	tr
	till	14 - 15'	L	40	38	22	tr
	till	19 - 20'	L	43	35	22	tr
	sand-lens	20 - 25'	SL	61	20	19	tr
	till	25 - 30'	CL	34	34	32	tr
	bedrock	33 - 34'	SiCL	15	51	34	tr
5 - 1	Ah	0 - 8"	L-SL	53	30	17	tr
	till	4 - 5'	L	40	35	25	tr
	bedrock	10 - 11'	SiC	8	46	46	tr
	bedrock	17 - 18'	SiC	10	43	47	tr
6 - 1	Ap	0 - 6"	L	49	30	21	tr
	bedrock	4 - 5'	L	48	29	23	tr
	bedrock	9 - 10'	L	48	27	25	tr
7 - 1	Ah	0 - 10"	SCL	48	10	22	tr
	bedrock	4 - 5'	SL	60	26	14	tr
	bedrock	9 - 10'	SCL	52	24	24	tr
	bedrock	14 - 15'	SCL	49	23	28	tr

* trace

Table 4. Mechanical Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Soil Class	Mechanical Analysis S	Si	C	Fine C
				%			
7 - 2	Ap	0 - 4"	L	48	29	23	tr*
	till	4 - 5'	L	44	33	23	tr
	till	14 - 15'	SL	63	20	17	tr
	till	27 - 28'	LS	82	11	7	0
	till	29 - 30'	SL	64	19	17	tr
	till	39 - 40'	L	48	29	23	tr
	till	44 - 45'	L	48	29	23	tr
	sand	53 - 54'	SL	68	19	13	tr
8 - 1	Ah	0 - 8"	SL	54	27	19	tr
	till	36 - 42"	L	49	30	21	tr
	till	9 - 10'	L	40	34	26	tr
	till	14 - 15'	L	46	28	26	tr
	till	19 - 20'	L	46	31	23	tr
	till	29 - 30'	L	45	30	25	tr
	till	39 - 40'	L	43	33	24	tr
	till	44 - 45'	L	45	29	26	tr
	bedrock	55 - 58'	CL-C	24	37	39	tr

* trace

The Canadian and U.S. limits of soil separates, which were used to determine the soil classes, are as follows:

VCS	1.00 - 2.00	mm.
CS	0.50 - 1.00	"
MS	0.25 - 0.50	"
FS	0.10 - 0.25	"
VFS	0.05 - 0.10	"
Si	0.002 - 0.05	"
C	< 0.002	"

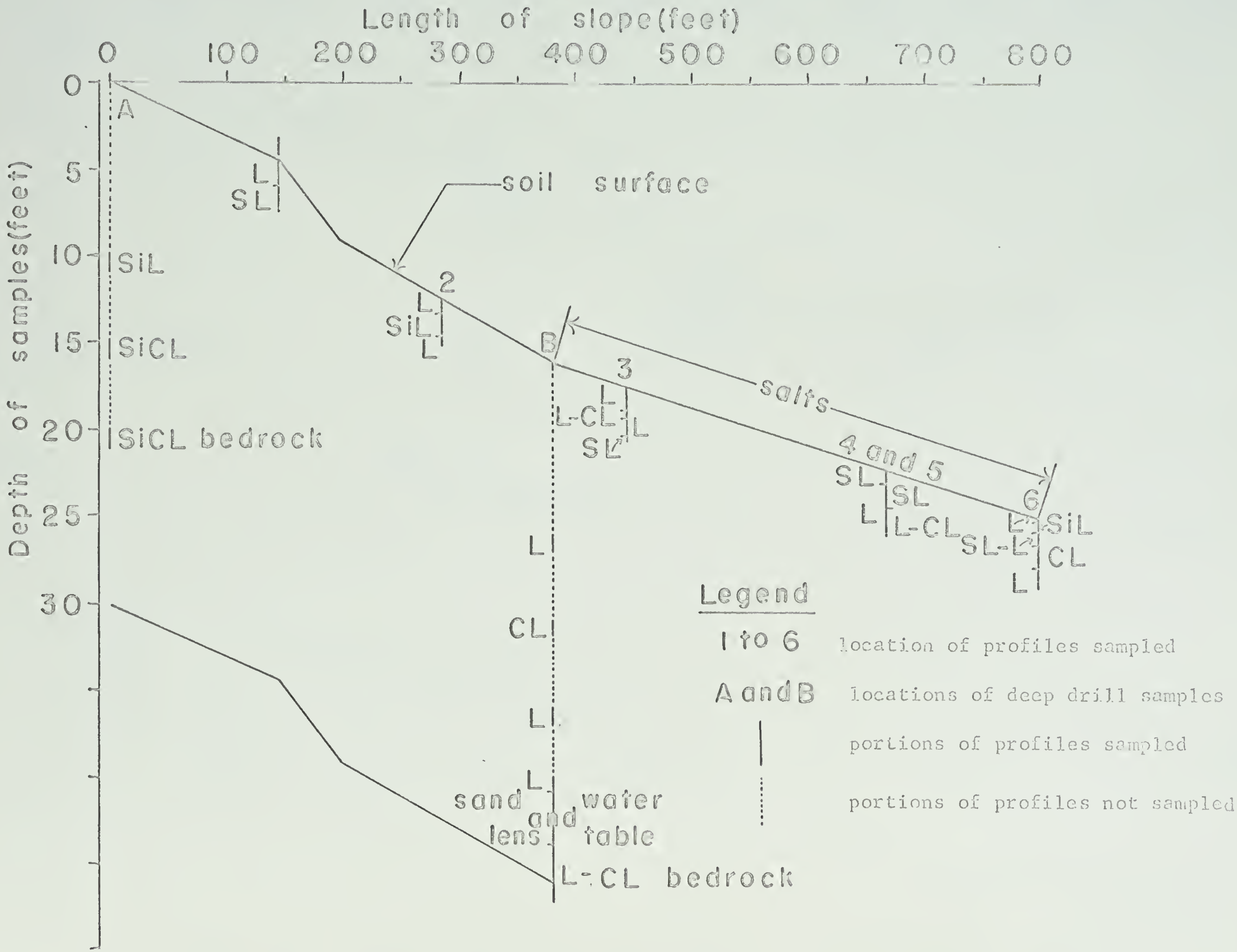


Figure 6a - schematic drawing of site 1, showing sample depths and textures

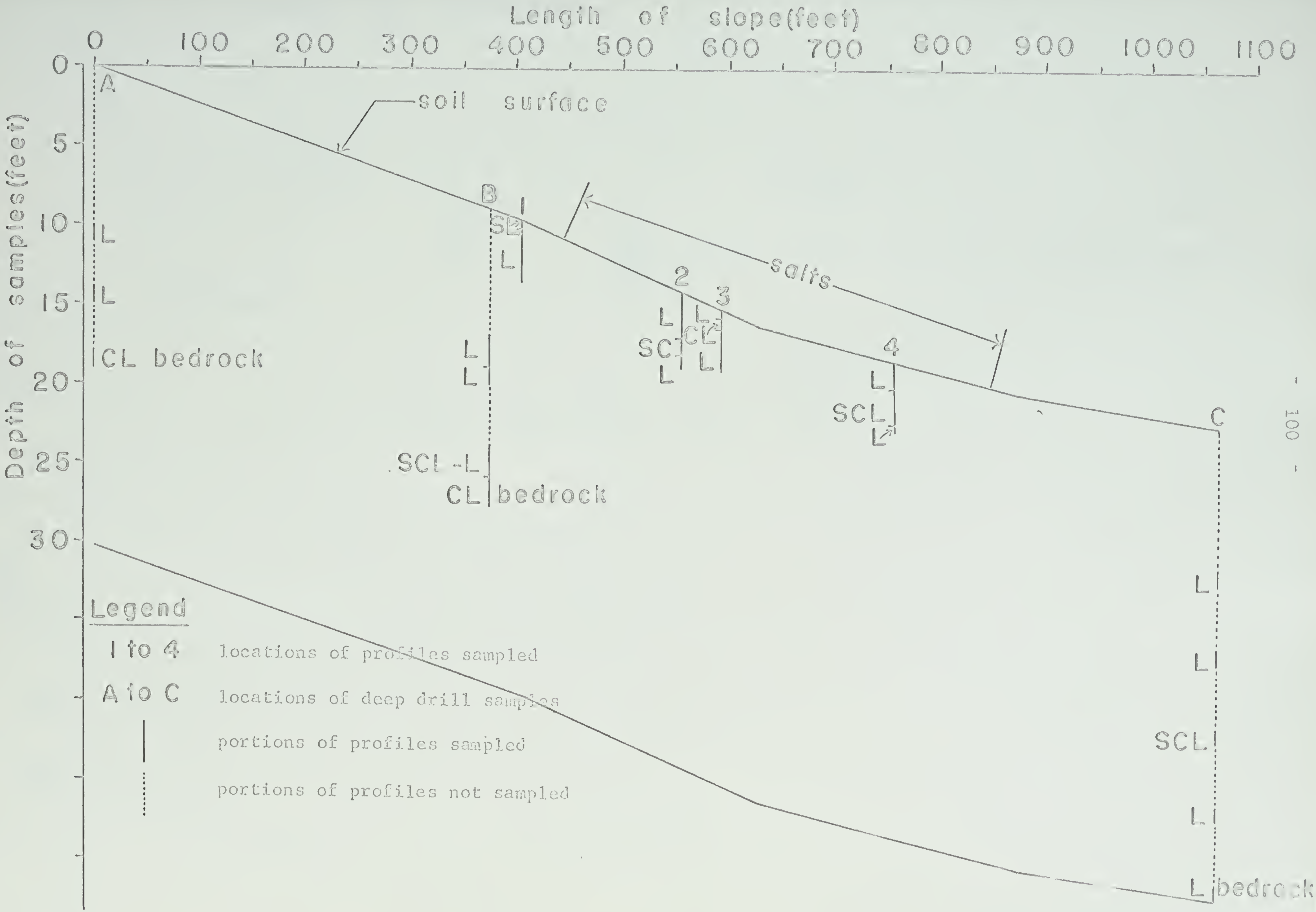


Figure 6b - schematic drawing of site 2, showing sample depths and textures

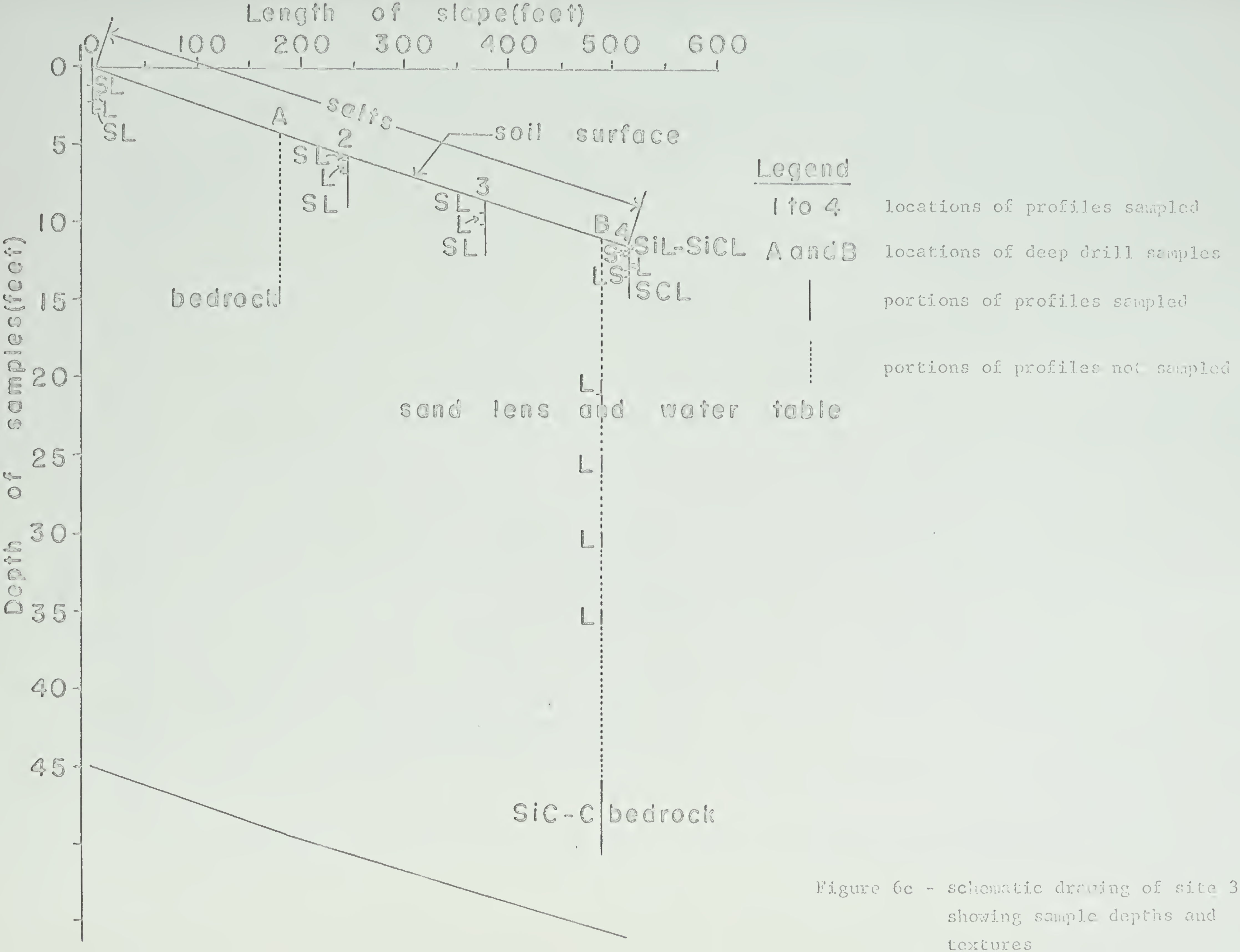
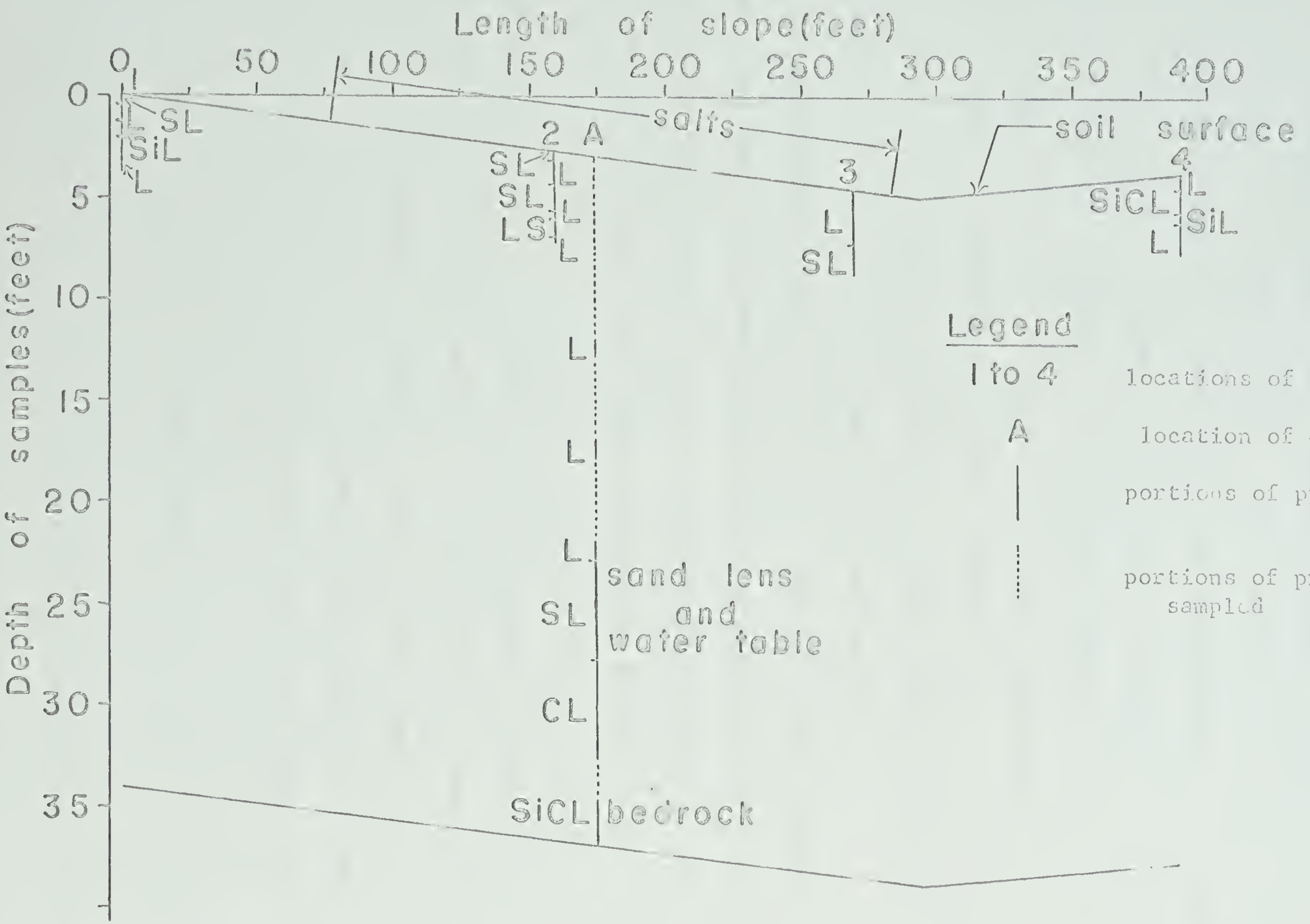


Figure 6c - schematic drawing of site 3 showing sample depths and textures



location of profiles sampled

location of deep drill sample

portions of profiles sampled

portions of profiles not sampled

Figure 6d - schematic drawing of site 4, showing sample depths and textures

The soils at site 2 were medium textured loams, with minor textural variations in the profiles (fig. 6b). The A horizon of profile 1 near the top of the slope was sandy loam, and the B horizon of profile 3 part way down slope was clay loam in texture. The B horizons of all the profiles except profile 2, part way down slope, meet the percentage clay requirement for Bt horizons. In general, the deep drill samples were loam in texture at site 2, with the exception of the bedrock samples in hole A, on top of the slope, and in hole B part way down slope, which were clay loam in texture. The depth to bedrock increased from 17 feet in holes A and B to 29 feet in hole C, indicating that the slope of the bedrock surface was steeper than the slope of the land surface.

In general, profiles 1 to 3 at site 3 had sandy loam surfaces and lower C horizons, with loam textures occurring either in the B or upper C horizons. This suggests that the soil materials are more or less isotropic in the down slope direction (fig. 6c). Profile 4, near the drainage course at the bottom of the slope, was highly stratified. A loam horizon at the 7 to 20 inch depth was overlain and underlain by sand lenses, and the lower sand lens was underlain by a sandy clay loam horizon. The B horizons of profiles 1 and 2 on the upper portion of the slope meet the percentage clay requirement for Bt horizons. Bedrock occurs at depths of 11 feet in deep drill hole A on the upper part of the slope, and at 44 feet in deep drill hole B near the base of the slope. There is evidently a steeper slope to the bedrock surface than to the overlying land surface. In general, the textures of the samples were loam in deep drill hole B, with the exception of a water-saturated sand lens at the 15 to 17-foot depth.

In general, the soils at site 4 were medium-textured loams, and

minor variations occurred in the profiles (fig. 6d). The A horizons of profiles 1 and 2, near the top of the longer slope and part way down the longer slope respectively, were sandy loam in texture. The Bt horizon of profile 4, near the top of the shorter slope, was silty clay loam in texture. Considerable stratification occurred in profile 2, which had sand lenses at the 19 to 35-inch and the 40 to 51-inch depths. A sand lens was also present at the 32 to 50-inch depth of profile 3, near the bottom of the longer slope. The B horizons of all the profiles at site 4 meet the percentage clay requirement for Bt horizons. In deep drill hole A, part way down the longer slope, the samples were loam in texture to the 20 to 25-foot depth, where a water-saturated sand lens occurred. The sand lens was underlain by clay loam till, a condition which would seem to be ideal for the movement of ground water. Silty clay loam bedrock occurred at 33 feet.

Textures of samples collected at sites 5 to 8 were similar to textures of samples collected at sites 1 to 4.

Chemical Analyses

Soil Reaction: The pH values of the soils studied (table 6) ranged from 5.7 to 8.4 in the A horizons, from 6.7 to 8.7 in the B horizons, and from 7.7 to 8.9 in the C horizons. A gradual increase in pH occurred with depth in the soil. pH values ranged from 8.0 to 8.5 in sand lenses of saline profiles and deep drill samples. Till samples had pH values ranging from 7.4 to 8.7, while pH values of bedrock samples varied from 7.6 to 8.5

Electrical Conductivity and Soluble Salts:

Electrical conductivity and soluble salt analyses are reported in table 6. Soluble salt analysis was not conducted on samples with electrical conductivity of less than 2, since crop growth is usually not hindered.

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts: total an. or cat. (EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
1 - 1	Ah	0 - 2½"	7.6	1.09	38	0.4	-	-	-	-	-	-	-	-	-
	Bt	2½ - 10"	7.7	0.78	41	0.3	-	-	-	-	-	-	-	-	-
	Cca	10 - 18"	7.9	0.52	48	0.3	-	-	-	-	-	-	-	-	-
	C-till	18 - 35"	8.3	1.00	3.0	0.3	-	-	-	-	-	-	-	-	-
1 - 2	Ahsa	0 - 2½"	7.5	10.0	41	4.1	2.1	0.1	1.0	1.4	4.6	0.3	4.2	0.3	4.8
	Btsa	2½ - 10½"	7.7	7.7	57	4.4	2.4	0	0.5	1.3	4.2	0.3	5.5	0.3	6.1
	BCsa	10½ - 16½"	8.4	2.1	75	1.6	1.0	tr*	0.1	0.2	1.3	0.1	1.2	0.4	1.7
	Cca	16½ - 26½"	8.6	1.73	61	1.1	-	-	-	-	-	-	-	-	-
	C-till	26½ - 34"	8.6	1.13	68	0.8	-	-	-	-	-	-	-	-	-
1 - 3	Ahksa	0 - 8"	8.2	20	56	16.8	9.9	tr	0.8	1.1	11.8	0.3	16.6	0.5	17.4
	Btksa	8 - 13"	8.5	14.6	79	11.5	8.9	tr	0.4	1.1	10.4	0.2	14.2	0.3	14.7
	BCksa	13 - 18"	8.7	12.2	94	11.5	13.4	tr	0.2	1.1	14.7	0.2	15.2	0.3	15.7
	Ccasa	18 - 24"	8.7	14.9	98	14.6	16.3	tr	0.4	1.9	18.6	0.2	22.1	0.4	22.7
	C-till	24 - 36"	8.6	8.9	105	9.4	7.5	tr	0.3	0.7	8.5	0.1	11.3	0.3	11.7

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts: total an. or cat. (EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
1 - 3 (cont.)	C-till	36 - 38"	8.7	5.8	76	4.4	3.2	tr*	0.1	0.2	3.5	0.1	4.2	0.2	4.5
1 - 4	Ahksa	0 - 4½"	8.4	20 +	42	12.6	29.1	tr	1.7	4.7	35.5	1.0	44.7	0.7	46.4
	Bmksa	4½ - 9½"	8.4	20 +	43	12.9	25.6	0.1	1.3	4.9	31.9	0.6	40.4	0.5	41.5
	Ccasa	9½ - 15"	8.8	20 +	53	15.9	23.1	0.1	1.5	6.4	31.1	0.2	37.0	0.3	37.5
	C-till	15 - 38"	8.8	20 +	67	20.1	15.4	0.1	0.8	3.8	20.1	0.1	19.8	0.2	20.1
1 - 5	Ahksa	0 - 7"	8.3	20 +	40	12.0	33.0	0.1	1.5	2.9	37.5	tr	51.2	0.6	51.8
	Bmksa	7 - 13"	8.7	20 +	51	15.3	22.6	tr	1.1	2.8	26.5	tr	26.7	0.4	27.3
	Ccasa	13 - 26"	8.7	20 +	43	12.9	18.6	0.1	1.2	4.5	24.4	tr	35.1	0.1	35.2
	C-till	26 - 40"	8.6	20 +	61	18.3	16.7	0.1	1.3	4.2	22.3	tr	30.8	0.2	31.0
1 - 6	Ahkg	0 - 4"	8.2	20 +	71	21.1	25.5	0.3	2.0	4.1	31.9	0.6	41.0	1.7	43.3
	Bkg	4 - 10"	8.5	20	54	16.4	9.4	0.1	0.7	1.4	11.6	0.2	11.1	0.5	11.8
	Ccag	10 - 20"	8.4	16	51	12.2	6.0	0.1	0.6	1.5	8.2	0.2	13.6	0.1	13.9
	C-lacustrine	20 - 36"	8.4	18	62	16.7	8.6	0.1	0.7	2.5	11.9	0.3	15.1	0.1	15.5
	C-lacustrine	36 - 42"	8.4	11	59	6.5	4.9	tr	0.5	1.4	6.8	0.1	11.8	0.1	12.0
2 - 1	Ap	0 - 6"	7.4	1.01	38	0.4	-	-	-	-	-	-	-	-	-

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts									
						total an. or cat. (EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
2 - 1	Bt	6 - 12"	6.7	0.63	43	0.3	-	-	-	-	-	-	-	-	-
(cont.)	BC	12 - 14"	7.2	0.77	43	0.3	-	-	-	-	-	-	-	-	-
	Cca	14 - 24"	7.7	0.64	40	0.3	-	-	-	-	-	-	-	-	-
	C-till	24 - 36"	7.8	0.74	41	0.3	-	-	-	-	-	-	-	-	-
	C-till	36 - 48"	7.7	2.1	43	0.9	0.4	tr*	0.3	0.3	1.0	tr	0.9	0.1	1.0
2 - 2	Ap	0 - 5"	6.3	4.9	37	1.8	0.7	0.1	1.1	0.6	2.5	tr	2.3	0.2	2.5
	Bmsa	5 - 8"	7.3	11.6	38	4.4	4.2	0.1	1.0	1.1	6.4	0.1	6.4	0.2	6.7
	Ccasa	8 - 20"	7.9	9.9	37	3.7	2.8	0.1	0.9	1.0	4.8	0.1	4.7	0.1	4.9
	C-till	20 - 36"	7.8	7.3	35	2.6	1.8	tr	0.7	0.9	3.4	0.1	3.4	0.1	3.6
	C-till	36 - 48"	7.7	6.6	33	2.2	1.3	tr	0.8	0.6	2.7	tr	3.0	0.1	3.1
	C-till	48 - 60"	7.7	7.7	37	2.8	1.9	tr	0.9	0.7	3.5	tr	3.8	0.1	3.9
2 - 3	Ap	0 - 6"	6.9	12.5	37	4.6	2.9	0.1	0.9	1.3	5.1	0.2	5.4	0.2	5.8
	Btsa	6 - 14"	7.4	14.6	41	5.0	4.1	tr	0.9	1.5	6.5	0.2	8.4	0.2	8.8
	Cca	14 - 24"	8.1	11.8	38	4.5	3.3	tr	0.9	0.8	5.0	0.1	6.2	0.1	6.4
	C-till	24 - 36"	8.2	12.8	41	5.3	3.7	tr	1.0	1.1	5.8	0.1	8.1	0.1	8.3
	C-till	36 - 48"	8.1	12.3	41	5.0	4.2	0	0.9	0.5	5.6	tr	7.8	0.1	7.9

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts: total an. or cat. (EC)	Na^{+}	K^{+}	Ca^{++}	Mg^{++}	total cations	Cl^{-}	$SO_4^{=}$	HCO_3^{-}	total anions
						me./100 gms. soil									
2 - 4	Apsa	0 - 9"	7.9	20 +	43	12.9	13.4	tr*	1.0	3.3	17.7	0.3	17.1	0.3	17.7
	Ccasa	9 - 20"	8.6	8.1	82	6.6	3.0	tr	0.3	0.5	3.8	tr	7.3	0.2	7.5
	C-till	20 - 48"	8.8	4.6	141	6.5	4.0	tr	tr	0.4	4.4	0.1	6.5	0.4	7.0
	C-till	48 - 54"	8.9	2.7	108	2.9	1.0	tr	tr	0.1	2.0	tr	2.4	0.5	2.9
3 - 1	Ap	0 - 5"	6.6	0.81	33	0.3	-	-	-	-	-	-	-	-	-
	Bt	5 - 11"	7.3	1.04	40	0.4	-	-	-	-	-	-	-	-	-
	Bmk	11 - 15"	7.6	1.20	35	0.4	-	-	-	-	-	-	-	-	-
	Cca	15 - 27"	7.6	4.0	39	1.6	0.4	tr	1.1	1.0	2.5	tr	2.4	0.1	2.5
	C-till	27 - 34"	7.8	8.4	24	2.0	1.1	tr	0.8	1.1	3.0	tr	2.7	0.1	2.8
3 - 2	Apsa	0 - 4"	6.3	11.5	33	3.8	3.4	tr	0.7	1.2	5.3	0.1	5.0	0.1	5.2
	Btsa	4 - 13"	7.5	11.3	43	4.9	5.6	tr	0.9	1.2	7.7	0.1	6.3	0.2	6.6
	BCksa	13 - 16"	7.7	11.7	48	5.6	6.9	tr	0.9	1.6	9.4	0.1	8.6	0.1	8.8
	Ccasa	16 - 31"	8.1	10.4	34	3.5	3.7	tr	0.8	0.8	5.3	0.1	4.9	0.1	5.1
	C-till	31 - 42"	8.3	5.5	38	2.1	2.1	tr	0.1	0.3	2.5	tr	2.6	0.1	2.7
3 - 3	Ap	0 - 5"	7.1	8.6	32	2.8	2.2	tr	0.7	0.7	3.6	tr	3.4	0.1	3.5
	Bm	5 - 11"	7.6	10.9	35	3.8	2.9	tr	0.7	0.7	4.3	tr	5.6	0.2	5.8
	Ccasa	11 - 21"	8.1	18	40	10.8	6.8	tr	0.8	0.9	8.5	0.1	6.5	0.1	6.7
	C-till	21 - 44"	8.3	18	24	6.5	3.6	tr	0.6	0.8	5.0	0.1	4.7	0.1	4.9

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts: total an. or cat. (EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
3 - 4	Ahsa	0 - 3"	7.7	20 +	60	18.0	16.6	0.2	1.3	1.9	20.0	0.2	22.6	0.7	23.5
	sand lens	3 - 7"	8.0	20 +	22	6.6	8.0	0.1	0.6	0.7	9.4	0.1	12.1	0.1	12.3
	alluvial	7 - 20"	7.8	20 +	46	13.8	44.2	0.2	1.3	8.2	53.9	0.5	59.4	0.5	60.4
	sand lens	20 - 24"	8.4	20 +	26	7.8	10.8	0.1	0.7	4.0	15.6	0.4	21.9	0.2	22.5
	till	24 - 40"	8.3	20 +	43	12.9	9.4	0.1	1.0	2.8	13.3	0.3	15.2	0.1	15.6
4 - 1	Apsa	0 - 5"	7.7	17	38	9.7	3.2	tr*	1.0	6.3	10.5	0.2	10.1	0.2	10.5
	Btsa	5 - 14"	7.6	11.6	49	5.7	2.6	tr	1.2	5.1	8.9	0.1	8.0	0.1	8.2
	Ccasa	14 - 24"	7.9	8.4	44	3.7	1.5	tr	1.0	2.7	5.2	0.1	4.7	0.1	4.9
	C-till	24 - 45"	7.8	5.1	36	1.8	0.6	tr	0.3	2.3	3.2	tr	2.5	0.1	2.6
4 - 2	Apsa	0 - 5"	7.4	13.7	35	4.8	2.9	0.1	0.7	3.6	7.3	0.1	6.6	0.2	6.9
	Btsa	5 - 14"	7.2	7.7	37	2.9	1.2	tr	0.6	2.1	3.9	0.1	3.7	0.1	3.9
	Ccasa	14 - 19"	7.8	8.1	41	3.3	1.3	tr	0.7	2.6	4.6	0.1	4.4	0.1	4.6
	C-sand lens	19 - 35"	7.7	7.6	24	1.8	0.7	tr	0.4	1.2	2.3	tr	2.5	0.1	2.6
	C-till	35 - 40"	7.6	6.6	43	2.8	0.9	tr	0.9	2.2	4.0	tr	4.3	0.1	4.4
	C-sand lens	40 - 51"	7.7	7.0	27	1.9	0.8	tr	0.5	1.3	2.6	tr	2.4	0.1	2.5
	C-till	51 - 56"	7.7	5.5	46	2.5	0.9	tr	0.6	1.8	3.3	tr	3.5	0.1	3.6

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts: total an. or cat. (EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
4 - 3	Apsa	0 - 4"	6.7	10.5	36	3.8	2.1	0.1	1.0	1.9	5.1	0.3	4.4	0.2	4.9
	Btsa	4 - 12"	7.2	9.4	47	4.4	2.4	tr*	1.0	3.0	6.4	0.3	5.6	0.2	6.1
	Cca	12 - 18"	7.7	7.0	41	2.9	1.2	tr	0.8	2.3	4.3	0.2	3.8	tr	4.0
	C-till	18 - 32"	7.7	7.0	4.0	2.8	1.2	tr	0.9	2.8	4.9	0.1	3.6	tr	3.7
	C-sand lens	32 - 50"	7.7	9.0	27	2.4	1.0	tr	0.7	2.0	3.7	0.1	3.4	0.1	3.6
4 - 4	Ap	0 - 6"	6.2	0.63	34	0.2	-	-	-	-	-	-	-	-	-
	Bt	6 - 20"	7.1	1.01	44	0.4	-	-	-	-	-	-	-	-	-
	Cca	20 - 26"	7.7	4.9	41	2.0	0.4	tr	0.9	1.9	3.2	tr	3.5	0.1	3.6
	C-till	26 - 46"	7.9	5.4	36	1.9	0.8	tr	0.4	1.6	2.8	tr	2.4	0.1	2.5
1 - A	lacustrine	9 - 10'	7.9	3.2	57	1.8	1.3	tr	0.2	0.4	1.9	tr	2.1	0.2	2.3
	lacustrine	14 - 15'	8.1	2.4	55	1.3	0.8	tr	0.2	0.2	1.2	tr	1.4	0.1	1.5
	bedrock	19 - 20'	8.2	1.21	47	0.6	-	-	-	-	-	-	-	-	-
1 - B	till	9 - 10'	8.1	16	67	10.7	10.3	0.1	1.4	2.4	14.2	tr	17.8	0.1	17.9
	lacustrine	14 - 15'	8.1	11.9	88	10.5	8.8	0.1	1.8	2.2	12.9	tr	18.2	0.1	18.3
	lacustrine	19 - 20'	8.2	4.5	97	4.4	3.2	tr	0.4	0.6	4.2	tr	5.6	0.3	5.9
	lacustrine	24 - 25'	8.1	12.9	67	8.6	6.1	0.1	1.3	1.8	9.3	tr	14.4	0.1	14.5
	bedrock	29 - 30'	8.1	1.81	52	0.9	-	-	-	-	-	-	-	-	-

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts									
						total an. or cat. (EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
1 - C	till	3 - 4'	8.4	16	53	12.7	6.3	0.1	0.5	2.9	9.8	0.1	9.9	0.1	10.1
	saline till	7 - 8'	7.7	9	85	7.8	5.3	0.1	1.8	2.3	9.5	tr*	9.4	0.1	9.5
	bedrock	9 - 10'	7.7	12	127	15.2	1.1	0.1	0.2	5.8	16.2	0.2	10.7	0.2	11.1
2 - A	till	9 - 10'	7.7	6.2	45	2.8	1.5	tr	0.9	1.9	4.3	tr	4.6	0.1	4.7
	till	14 - 15'	7.7	5.4	39	2.1	1.2	tr	0.9	0.9	3.0	tr	3.4	0.1	3.5
	bedrock	17 - 18'	7.9	2.7	54	1.5	0.9	tr	0.3	0.3	1.5	tr	0.6	0.1	1.7
2 - B	till	8 - 10'	8.0	3.1	49	1.5	0.2	tr	0.1	0.4	0.7	tr	1.8	0.2	2.0
	till	10 - 11'	8.0	2.8	54	1.5	1.2	tr	0.1	0.2	1.5	tr	1.7	0.2	1.9
	till	14 - 15'	8.0	2.6	63	1.6	1.1	tr	0.2	0.2	1.5	tr	1.7	0.2	1.9
	bedrock	17 - 19'	7.9	2.8	57	1.6	0.2	tr	0.1	0.2	0.5	tr	1.6	0.2	1.8
2 - C	lacustrine	9 - 10'	7.8	1.27	38	0.5	-	-	-	-	-	-	-	-	-
	lacustrine	14 - 15'	8.0	1.01	41	0.4	-	-	-	-	-	-	-	-	-
	lacustrine	19 - 20'	7.6	4.3	42	1.8	0.7	tr	1.0	0.9	2.6	tr	1.8	0.1	1.9
	till	24 - 25'	7.7	4.5	44	2.0	0.7	tr	0.9	0.9	2.5	tr	2.1	0.1	2.2
	bedrock	29 - 30'	7.6	5.7	44	2.5	1.4	tr	0.9	1.0	3.3	tr	4.3	0.1	4.4

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts									
						total an. or cat.(EC)	Na^+	K^+	Ca^{++}	Mg^{++}	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gms. soil									
3 - B	till	9 - 10'	7.8	8.5	56	4.8	2.7	tr*	1.2	0.8	5.7	tr	7.0	0.1	7.1
	till	14 - 15'	7.7	7.6	40	3.0	2.1	tr	0.9	0.4	3.4	tr	4.6	0.1	4.7
	till	19 - 20'	8.2	2.02	3.9	0.8	0.5	tr	tr	0.1	0.6	tr	0.7	0.2	0.9
	till	24 - 25'	8.2	1.83	35	0.6	-	-	-	-	-	-	-	-	-
	bedrock	44 - 45'	8.3	1.74	64	1.1	-	-	-	-	-	-	-	-	-
4 - A	till	9 - 10'	7.6	6.6	44	2.9	1.2	tr	0.9	2.2	4.3	tr	5.3	0.1	5.4
	till	14 - 15'	7.6	5.2	47	2.5	1.2	tr	0.9	1.4	3.5	tr	3.9	0.1	4.0
	till	19 - 20'	7.5	4.4	49	2.2	0.8	tr	1.0	0.2	2.0	0.1	3.1	0.1	3.3
	sand lens	24 - 25'	7.6	2.8	40	1.1	0.4	tr	0.4	0.3	1.2	tr	1.3	0.1	1.4
	till	29 - 30'	7.8	0.82	61	0.5	-	-	-	-	-	-	-	-	-
	bedrock	33 - 34'	7.8	0.81	63	0.5	-	-	-	-	-	-	-	-	-
5 - 1	Ah	0 - 8"	7.9	5.5	47	2.6	3.7	-	-	-	-	-	2.3	-	-
	till	4 - 5'	8.7	16	66	15.8	10.1	tr	0.6	0.1	10.8	tr	13.2	0.3	13.5
	bedrock	10 - 11'	8.3	1.62	72	1.2	-	-	-	-	-	-	-	-	-
	bedrock	17 - 18'	8.5	1.50	67	1.0	-	-	-	-	-	-	-	-	-
6 - 1	Ap	0 - 6"	5.7	0.12	33	tr	-	-	-	-	-	-	-	-	-
	bedrock	4 - 5'	7.8	0.51	43	0.2	-	-	-	-	-	-	-	-	-
	bedrock	9 - 10'	7.9	0.43	48	0.2	-	-	-	-	-	-	-	-	-

* trace

Table 5. pH and Soluble Salt Analyses of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	pH	Conductivity mmhos. per cm.	Saturation %	Soluble Salts: total an. or cat. (EC)	Na^+	K^+	Ca^+	Mg^+	total cations	Cl^-	$SO_4^=$	HCO_3^-	total anions
						me./100 gm. soil									
7 - 1	Ah	0 - 10"	6.7	0.56	60	0.3	-	-	-	-	-	-	-	-	-
	bedrock	4 - 5'	8.1	0.48	34	0.2	-	-	-	-	-	-	-	-	-
	bedrock	9 - 10'	8.1	0.55	44	0.2	-	-	-	-	-	-	-	-	-
	bedrock	14 - 15'	8.0	0.57	42	0.2	-	-	-	-	-	-	-	-	-
7 - 2	Ap	0 - 4"	7.5	0.61	42	0.3	-	-	-	-	-	-	-	-	-
	till	4 - 5'	7.8	6.3	45	2.8	1.5	tr*	1.1	2.0	4.6	tr	4.2	0.1	4.3
	till	14 - 15'	7.8	8.0	35	2.8	1.6	tr	0.8	2.3	4.7	0.1	4.7	tr	4.8
	till	24 - 25'	7.4	6.4	27	1.7	1.1	tr	0.7	1.2	3.0	tr	2.6	0.1	2.7
	till	29 - 30'	7.5	6.5	35	2.3	1.4	tr	0.8	1.5	3.6	tr	3.3	0.1	3.4
	till	39 - 40'	7.5	4.4	42	1.9	0.7	tr	1.1	1.9	3.7	tr	2.6	0.1	2.7
	till	44 - 45'	7.5	4.1	45	1.9	0.8	tr	1.1	0.9	2.8	tr	2.6	0.1	2.7
	sand	53 - 55'	7.7	1.67	36	0.6	-	-	-	-	-	-	-	-	-
8 - 1	Ah	0 - 8"	6.2	0.60	38	0.2	-	-	-	-	-	-	-	-	-
	till	36 - 42"	7.8	0.64	41	0.3	-	-	-	-	-	-	-	-	-
	till	9 - 10'	7.6	6.2	44	2.7	1.3	tr	1.0	2.0	4.3	tr	4.1	0.1	4.5
	till	14 - 15'	7.5	5.5	46	5.5	1.3	tr	1.1	1.6	4.0	tr	3.6	0.1	3.7
	till	19 - 20'	7.6	4.9	42	2.1	0.8	tr	1.1	1.0	2.9	tr	2.8	0.1	2.9
	till	29 - 30'	7.5	4.7	46	2.2	0.9	tr	1.2	0.9	3.0	tr	2.8	0.1	2.9
	till	39 - 40'	7.5	4.9	47	2.3	0.9	tr	1.2	0.9	3.0	tr	3.0	0.1	3.1
	till	44 - 45'	7.6	4.8	45	2.2	1.1	tr	1.1	1.0	3.2	tr	3.0	0.1	3.1
	bedrock	55 - 58'	8.0	3.75	72	2.7	2.1	tr	0.6	0.3	3.0	tr	2.2	0.2	2.4

* trace

[illegible]

Electrical conductivity readings were used to classify the soils according to the salinity classification in Handbook 60. This classification is given in table 6.

Soluble salt analysis was conducted in order to evaluate salt concentration and composition in the various soil horizons and underlying geologic material. A saline horizon, designated as "sa" by the National Soil Survey Committee of Canada in 1963, is a horizon with

Table 6. Classification of Soil Salinity by Handbook 60

Soil	Electrical Conductivity (mmhos./cm.)	ESP*
Nonsaline - nonalkali	≤ 4	< 15
Saline	> 4	< 15
Saline - alkali	> 4	> 15
Nonsaline - alkali	≤ 4	> 15

* exchangeable sodium percentage

secondary enrichment of salts more soluble than carbonates where the concentration of salts exceeds that present in the unenriched parent material. A horizon with salts including gypsum which may be detected as crystals or veins, or as surface crusts of salt crystals, or by distressed crop growth, or the presence of salt tolerant plants, is designated as "s". A "saline soil" is defined as having saline A, B, and C horizons.

In general, sodium was the predominant cation comprising the soluble salts in the soils studied. Thus it would appear that the main source of salts is bedrock. Small amounts of calcium, and trace amounts of potassium were present. Sulfate was the predominant anion of the soluble salts in the soils studied, and this also suggests

that bedrock could be the main source of salts. Bicarbonate was present in very small amounts, while only trace amounts of chloride were present. It may be expected that any $CO_3^{=}$ present in the soil was hydrolyzed to HCO_3^- as a result of the presence of dissolved CO_2 in the leaching water.

At site 1, salt content in the soils increases down slope, and is highest in profiles 4 and 5 near the base of the slope (fig. 7a). The salt concentration of profiles 4 and 5, as determined by the electrical conductivity, is misleading, since salt concentration decreases with depth. The relative amount of magnesium, as compared to sodium, is higher in profiles 4 and 5 than elsewhere on the slope. This suggests that local ground water movement may occur at these locations. Saline A, B, and BC horizons occur in profile 2, while profiles 3 to 5 are saline soils (N.S.S.C.C., 1963).

The nature of salt accumulation on the slope at site 2 suggests that a perched water table could be the main factor causing high salt concentration (fig. 7b). There is a gradual increase in salinity down slope. The top of the slope is nonsaline, although salt concentration increases slightly with depth. Salt concentration is much higher approximately midway down slope. The highest salinity occurs in the B horizon of profiles 2 and 3, and decreases gradually with depth. At the base of the slope, the highest salt concentration occurs in the A horizon, and decreases rapidly with depth. Saline horizons occur in profiles 2 and 3, and profile 4 is a saline soil (N.S.S.C.C., 1963).

The salt accumulation on the slope at site 3 also likely results from the presence of a perched water table (fig. 7c). A gradual increase in salt concentration occurs down slope. The top of the slope is nonsaline,

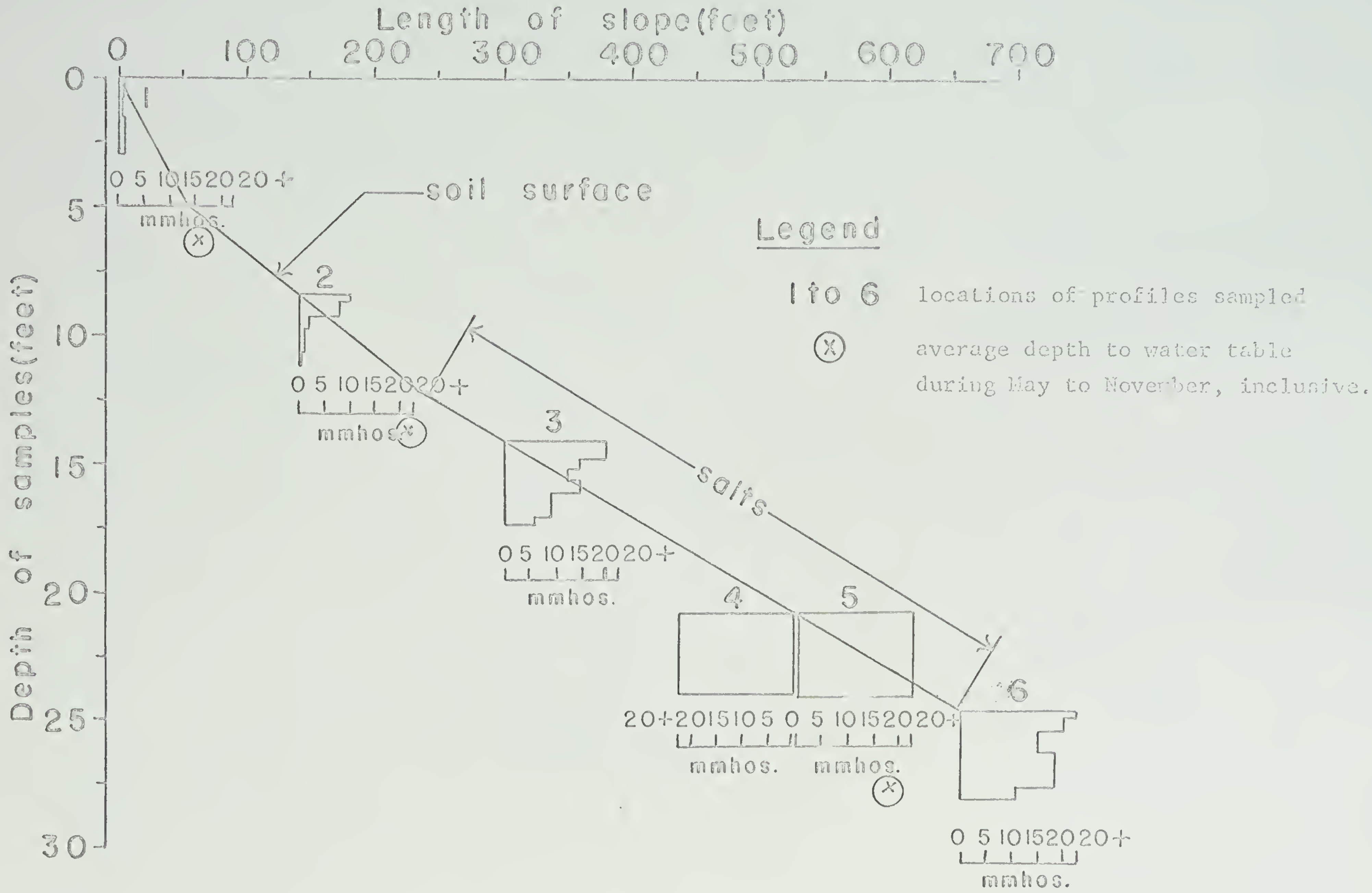


Figure 7a.- schematic drawing of site 1, indicating salt concentrations in different horizons of soil profiles

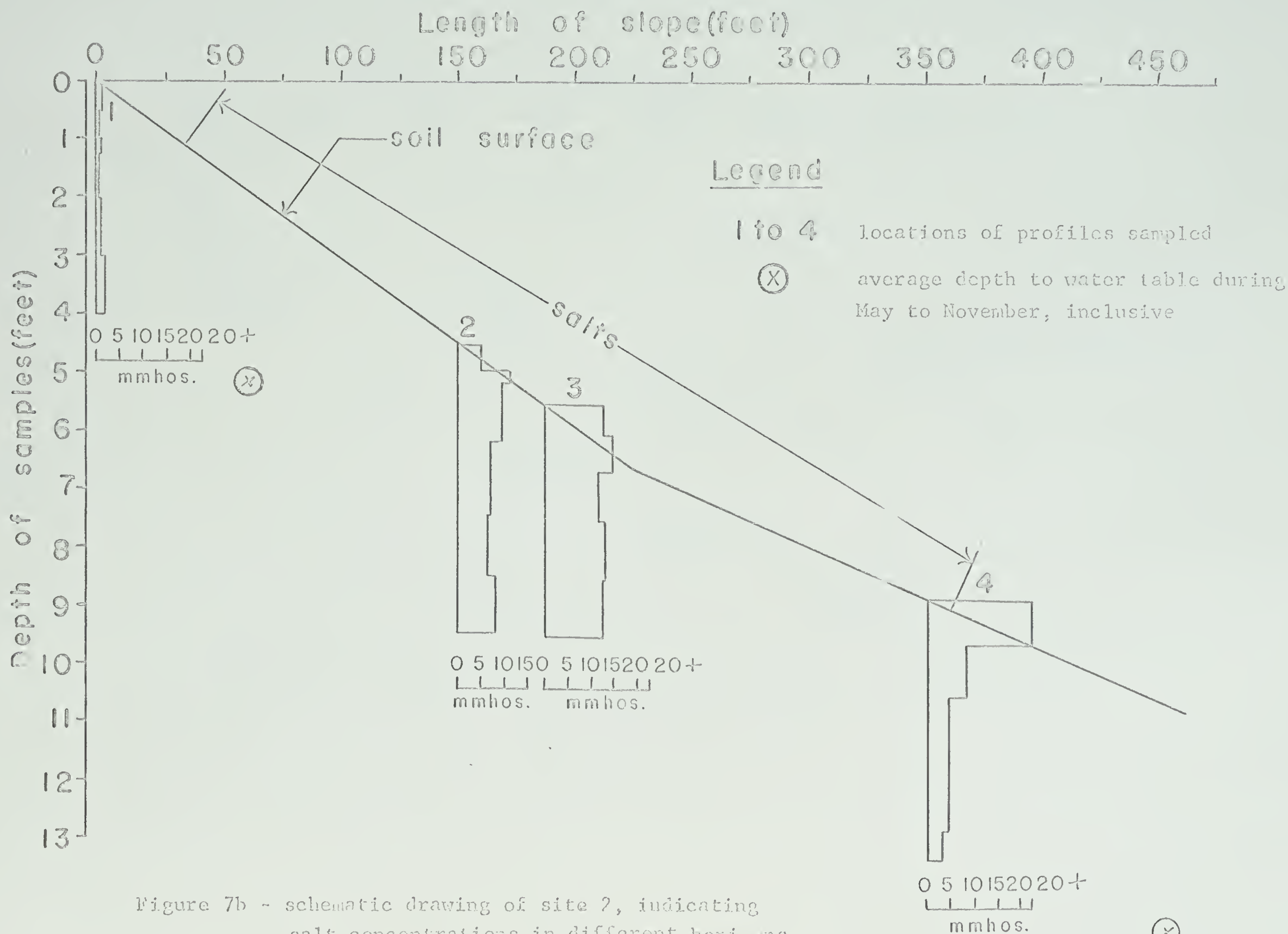


Figure 7b - schematic drawing of site 2, indicating salt concentrations in different hori ns of soil profiles

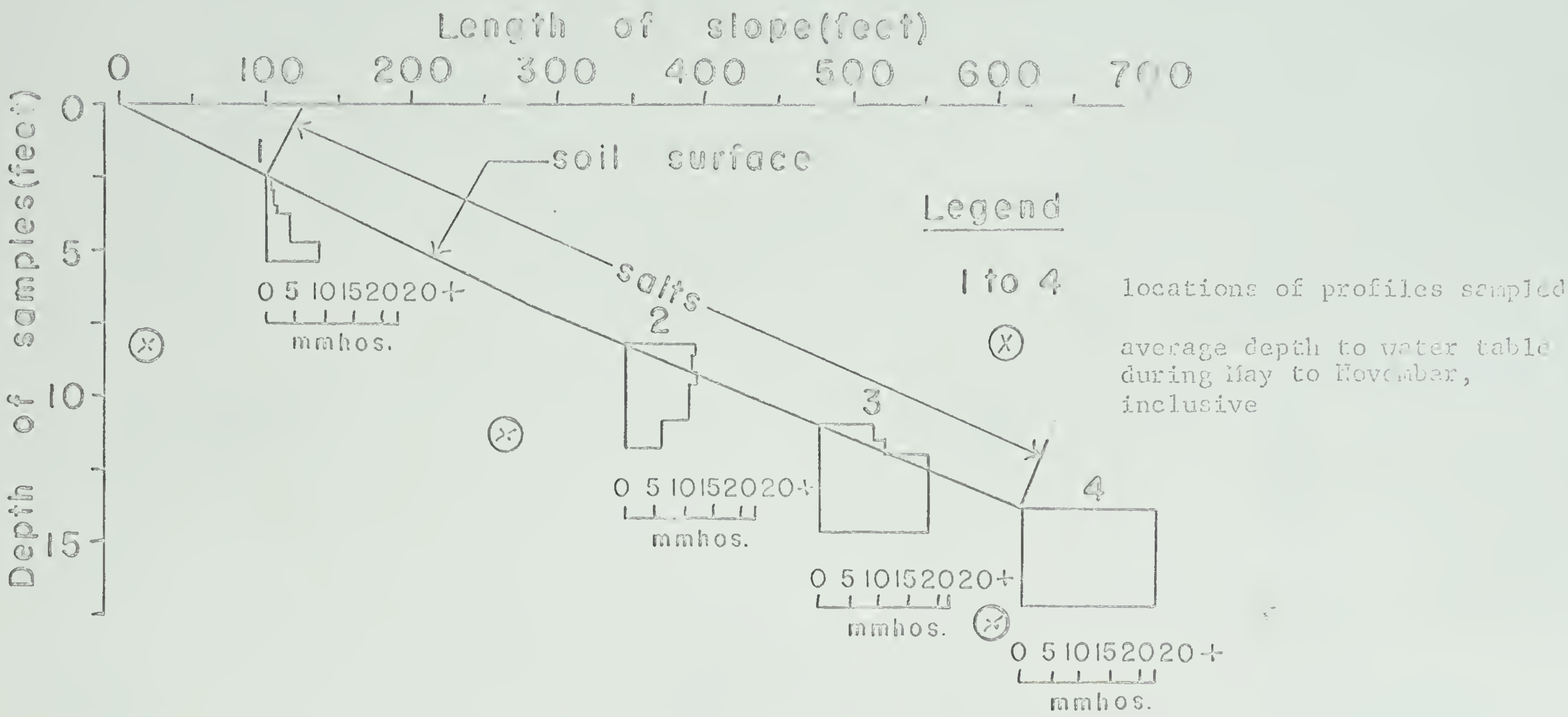


Figure 7c.- schematic drawing of site 3, indicating salt concentrations in different horizons of soil profiles

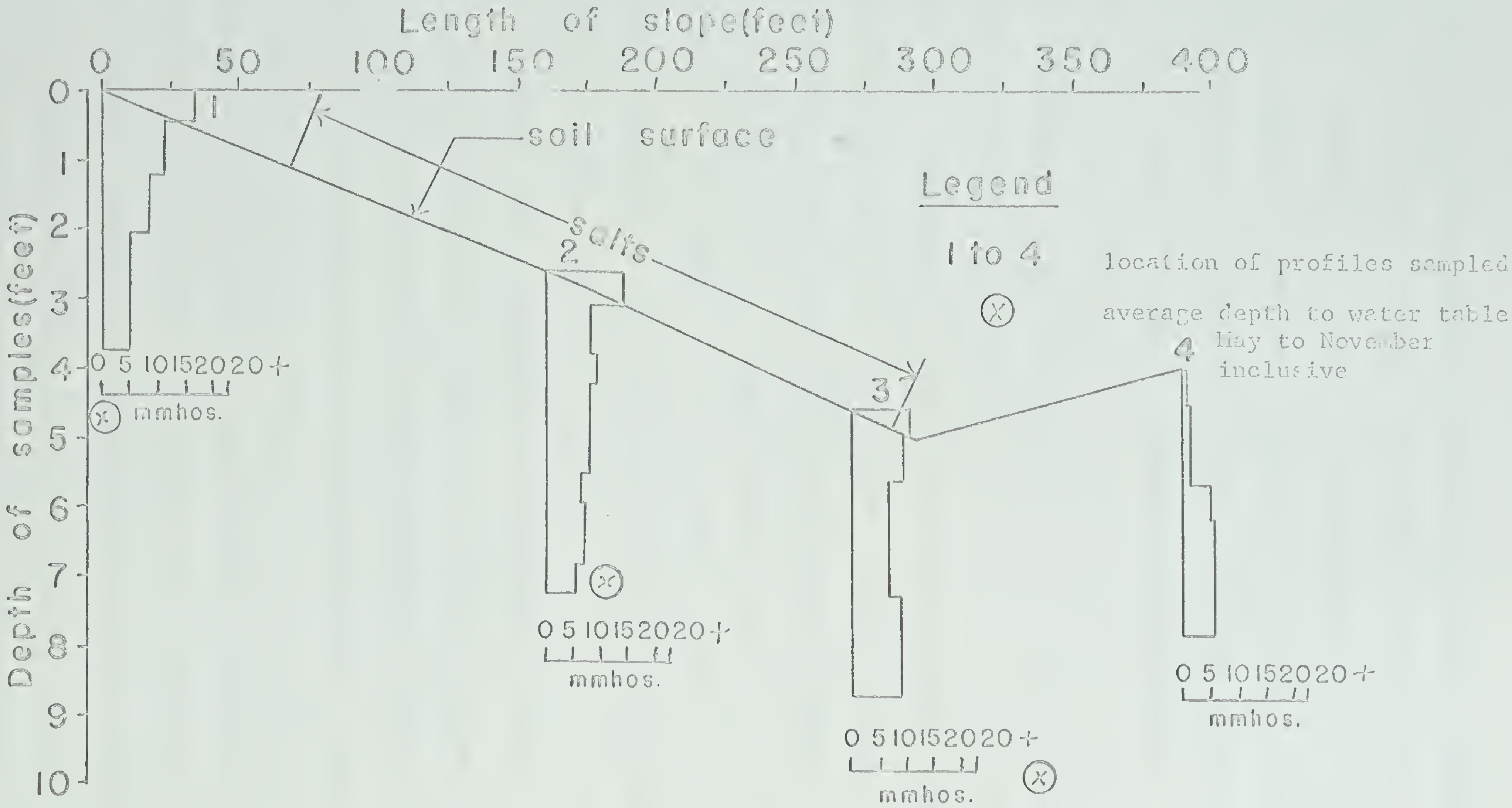


Figure 7d - schematic drawing of site 4, indicating salt concentrations in different horizons of soil profiles

although salinity increases substantially with depth. Magnesium concentration is as high as or higher than sodium concentration at the top of the slope. However, as salinity increases down slope, the relative amount of sodium, as compared to magnesium, increases steadily. The salt concentration, as determined by the electrical conductivity, is misleading in profiles 2 and 3. Maximum salt concentration occurs in the BCksa horizon of profile 2, and in the Ccasa horizon of profile 3. The degree of salintiy varies considerably in the different horizons developed from the alluvial deposition at the bottom of the slope. The highest salt concentration occurs in the medium-textured horizon at a depth of 7 to 20 inches from the surface. The salt concentration is much lower in the sand lenses above and below this horizon. A higher than normal concentration of magnesium occurs below the first sand lense in profile 4. This suggests a local origin of salts at the bottom of the slope. Profiles 2 and 4 are saline soils, and the Ccasa horizon of profile 3 is saline (N.S.S.C.C., 1963).

In general, salt concentration decreases down the long slope and up the short slope at site 4 (fig. 7d). This trend suggests that downward leaching of salts may increase progressively down the long slope. Maximum salt concentration on the long slope occurs on the surface, at the crown and part way down, and in the B horizon, at the base. The salt concentration, as determined by the electrical conductivity, is misleading in profile 3, since it shows the maximum salt concentration to be present on the surface. Maximum salt concentration occurs in the Btsa horizon. There is a gradual decrease in salt concentration with depth in the soil on the long slope, and this decrease is more gradual in profiles 2 and 3, than in profile 1 at the crown. The soil surface of the short slope is nonsaline, and a gradual increase in salinity occurs

[illegible]

[illegible]

with depth. This trend suggests that the depth to the water table may be greater beneath the short slope than beneath the long slope. The fact that magnesium occurs in higher concentrations than sodium at site 4, further suggests that salt concentration at this location may be caused mainly by local ground water movement. Profiles 1 and 2 were saline soils, while saline A and B horizons occurred in profile 3 (N.S.S.C.C., 1963).

In general, very low salinity was evident in deep till and bedrock samples. The predominant cation was sodium, with lesser amounts of magnesium. Calcium occurred in lower concentrations. At site 7-2 and site 8, magnesium occurred in slightly higher concentrations than sodium. The reason for this may be that the Thigh Hills, adjacent to site 7-2 to the south, is a local recharge area, and that salts at site 7-2 and site 8 are carried by local ground water flow.

The predominant anion that occurred in deep till and bedrock samples was sulfate. Very small amounts of bicarbonate, and only trace amounts of chloride were present.

Exchangeable Cations and Cation Exchange Capacity:

The ratios of exchangeable cations generally reflect the pedogenic processes which have been active in soil development. Exchangeable calcium and sodium percentages were used to obtain the ratio of per cent exchangeable Ca/ per cent exchangeable Na, since it was decided at the 1965 fall meeting of the National Soil Survey Committee of Canada that this ratio must be 10 or less in the B horizon if it is to meet the chemical requirements of a solonetzic B. Solonetzic B horizons must in addition have distinctive morphological and physical characteristics as shown by black or dark colorations or coatings on the surfaces of the

peds and characterized by prismatic or columnar structure, and hard to very hard consistency when dry. Exchangeable sodium percentages were also used to classify the soils according to the salinity classification in Handbook 60. The cation exchange capacity and exchangeable cations are reported in table 7.

In general, the cation exchange capacity parallels the distribution of clay in the soil and parent material samples analyzed. The cation exchange capacity as determined by summation differs from that found by direct determination. The large differences in the C horizons may be attributed to the presence of free calcium carbonate and soluble salts in soil voids. This is in agreement with the results obtained by other workers (Kelley, 1948) who have shown that soluble salts and calcium carbonate are more readily soluble in ammonium acetate solution than in water. In other horizons, cation exchange capacity found by ammonia distillation was generally lower than that found by summation. Similar results for such soils have been reported by other workers (Wells, 1961; Ballantyne and Clayton, 1964).

In all the soil and parent material samples tested, calcium was the predominant cation on the exchange complex, while magnesium was the next most abundant cation. In a few instances, there were higher quantities of sodium than magnesium. However, sodium was present in only slightly more than trace amounts when soluble salts were absent, or present in very low amounts in the soil voids. The highest concentrations of exchangeable potassium occurred in the A horizons. Substantial decreases were evident in the B horizons, and little more than trace amounts were found below this depth.

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations determined me. per 100 gms. soil	*Na^+ (% of total)	K^+ (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
1 - 1	Ah	0 - 2½"	19.7	0.4	4.4	75.8	19.4	25.1
	Bt	2½ - 10"	17.3	0.4	1.8	91.8	6.0	28.3
	Cca	10 - 18"	16.8	0.5	0.5	89.5	9.5	55.8
	C-till	18 - 35"	12.4	2.9	0.9	72.5	23.7	44.8
1 - 2	Ahsa	0 - 2½"	13.8	11.6	1.9	55.2	31.3	26.8
	Btsa	2½ - 10½"	19.4	20.5	2.2	24.2	53.1	27.7
	BC	10½ - 16½"	14.3	6.5	0.6	61.2	31.7	59.4
	Cca	16½ - 26½"	9.5	7.9	0.4	58.3	33.4	53.0
	C-till	26½ - 34"	12.6	5.1	0.4	63.5	31.0	51.3
1 - 3	Ahksa	0 - 8"	13.1	30.4	0.9	54.2	14.5	53.3
	Btksa	8 - 13"	13.8	25.7	0.5	57.2	16.6	62.6
	BCksa	13 - 18"	12.1	17.7	0.5	57.7	24.1	56.0
	Ccasa	18 - 24"	12.7	11.8	0.6	62.4	25.2	50.0
	C-till	24 - 36"	22.0	6.6	0.6	67.1	25.7	45.2
	C-till	36 - 38"	9.4	13.5	0.6	68.1	17.8	48.8

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	determined me. per 100 gms. soil	Total Exchangeable Cations $^{*}Na^{+}$	K^{+}	Ca^{++}	Mg^{++}	sum me. per 100 gms. soil
				% of total				
1 - 4	Ahksa	0 - 4½"	13.1	3.5	1.4	77.4	17.7	49.2
	Bmksa	4½ - 9½"	12.6	12.4	1.0	61.1	25.5	39.5
	Ccasa	9½ - 15"	11.9	24.1	0.5	56.8	18.6	63.0
	C-till	15 - 38"	12.0	22.0	0.5	55.7	21.8	58.1
1 - 5	Ahksa	0 - 7"	14.1	13.3	1.3	71.2	14.2	30.2
	Bmksa	7 - 13"	11.1	9.4	0.6	77.2	12.8	54.0
	Ccasa	13 - 26"	10.6	0.2	0.6	80.8	18.4	49.5
	C-till	26 - 40"	15.3	5.9	0.4	75.9	17.8	59.1
1 - 6	Ahkgsa	0 - 4"	29.0	9.0	2.6	65.5	22.9	46.8
	Bgksa	4 - 10"	9.2	9.9	1.3	67.2	21.6	46.3
	Ccagsa	10 - 20"	8.2	13.5	1.1	68.0	17.4	53.9
	C-lacustrine	20 - 36"	13.2	6.8	1.2	66.5	25.5	51.3
	C-lacustrine	36 - 42"	12.2	13.4	0.9	62.4	23.3	53.9
2 - 1	Ap	0 - 6"	18.3	1.7	3.8	83.8	10.7	23.4
	Bt	6 - 12"	19.5	1.6	2.2	72.0	24.2	18.6

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations: determined me. per 100 gms. soil	$*Na^{+}$ (% of total)	K^{+} (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
2 - 1 (cont.)	BC	12 - 14"	16.6	0.8	1.7	95.3	2.2	23.7
	Cca	14 - 24"	12.6	0.4	0.6	91.9	7.1	50.1
	C-till	24 - 36"	12.7	0.5	0.4	83.8	15.3	54.9
	C-till	36 - 48"	13.5	2.1	0.6	89.0	8.3	48.5
2 - 2	Ap	0 - 5"	16.9	5.3	5.3	61.8	27.6	43.1
	Bmsa	5 - 8"	17.1	8.4	2.7	53.4	35.5	22.5
	Ccasa	8 - 20"	10.2	5.3	0.6	72.1	22.0	65.9
	C-till	20 - 36"	11.1	5.4	0.6	83.6	10.4	53.3
	C-till	36 - 48"	9.8	2.8	0.3	90.4	6.5	88.6
	C-till	48 - 60"	15.9	4.7	0.5	79.9	14.9	57.2
2 - 3	Ap	0 - 6"	18.2	14.8	5.0	73.4	6.8	26.2
	Btsa	6 - 14"	18.4	23.5	2.2	46.4	27.9	39.1
	Ccasa	14 - 24"	15.2	9.7	0.5	74.9	14.9	62.3
	C-till	24 - 36"	14.4	9.1	0.4	80.9	9.6	68.1
	C-till	36 - 48"	13.8	3.5	0.2	94.0	2.3	126.0

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations: determined me. per 100 gms. soil	$*Na^+$ (% of total)	K^+ (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
2 - 4	Apsa	0 - 9"	12.0	16.0	0.9	30.8	52.3	55.1
	Ccasa	9 - 20"	12.2	19.7	0.3	70.1	9.9	60.6
	C-till	20 - 48"	13.6	19.9	0.6	62.8	16.7	52.8
	C-till	48 - 54"	12.2	16.6	0.6	62.1	20.7	53.5
3 - 1	Ap	0 - 5"	14.3	1.2	4.8	83.3	10.7	16.8
	Bt	5 - 11"	16.2	0.9	2.3	83.9	12.9	21.7
	Bmk	11 - 15"	14.6	0.6	1.2	93.6	4.6	32.5
	Cca	15 - 27"	9.9	1.0	0.4	90.3	8.3	51.4
	C-till	27 - 34"	5.4	0.5	0.3	90.0	8.3	59.3
3 - 2	Ap	0 - 4"	13.5	3.1	3.1	47.2	46.6	16.3
	Btsa	4 - 13"	15.0	15.1	2.0	46.1	36.8	25.2
	BCksa	13 - 16"	16.0	16.7	1.0	61.7	20.6	40.9
	Ccasa	16 - 31"	7.6	8.7	0.4	83.4	7.5	46.6
	C-till	31 - 42"	6.6	6.9	0.3	74.9	17.9	37.6

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

			Total Exchangeable Cations					
Site No. Profile No.	Horizon	Depth	determined me. per 100 gms. soil	$^{*}Na^{+}$	K^{+}	Ca^{++}	Mg^{++}	sum me. per 100 gms. soil
				% of total				
3 - 3	Ap	0 - 5"	13.2	7.0	4.1	59.8	29.1	17.2
	Bm	5 - 11"	12.5	16.4	1.4	64.9	17.3	28.0
	Ccasa	11 - 21"	9.7	7.2	0.6	87.3	4.9	51.2
	C-till	21 - 44"	4.3	2.8	0.1	91.7	5.4	79.0
3 - 4	Ahsa	0 - 3"	26.2	14.9	3.1	65.2	16.8	48.3
	sand lens	3 - 7"	3.5	13.2	2.6	81.6	2.6	7.6
	alluvial	7 - 20"	19.6	37.3	1.5	46.3	14.9	47.2
	sand lens	20 - 24"	4.8	8.4	0.5	69.6	21.5	40.4
	till	24 - 40"	13.4	7.1	0.3	86.0	6.6	97.1
4 - 1	Apsa	0 - 5"	15.1	4.9	1.3	62.0	31.8	37.9
	Btsa	5 - 14"	18.1	4.9	0.9	59.6	34.6	33.6
	Ccasa	14 - 24"	14.0	1.5	0.4	77.1	21.0	55.9
4 - 2	Apsa	0 - 5"	16.6	7.8	2.6	62.2	27.4	30.6
	Btsa	5 - 14"	16.3	7.5	1.8	54.0	36.7	22.6

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations: determined me. per 100 gms. soil	$^*Na^+$ (% of total)	K^+ (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
4 - 2 (cont.)	Ccasa	14 - 19"	11.9	4.0	0.3	78.1	17.6	57.5
	C-sand lens	19 - 35"	5.9	2.5	0.3	80.6	16.6	37.2
	C-till	35 - 40"	15.1	1.4	0.5	74.4	23.7	62.7
	C-sand lens	40 - 51"	7.0	2.3	0.6	75.5	21.6	31.0
	C-till	51 - 56"	15.6	2.5	0.5	64.4	32.6	55.7
4 - 3	Apsa	0 - 4"	15.9	12.1	3.3	50.0	34.6	30.6
	Btsa	4 - 12"	19.2	4.1	1.6	59.8	34.5	36.6
	Cca	12 - 18"	12.8	1.2	0.5	82.6	15.7	56.1
	C-till	18 - 32"	11.4	1.4	0.6	85.6	12.4	48.4
	C-sand lens	32 - 50"	7.3	2.1	1.1	64.9	31.9	28.2
4 - 4	Ap	0 - 6"	15.8	1.0	4.3	66.6	28.1	21.0
	Bt	6 - 20"	23.4	1.0	2.0	70.4	26.6	30.4
	Cca	20 - 26"	10.4	0.8	0.6	85.9	12.7	50.5
	C-till	26 - 46"	10.0	1.1	0.4	68.3	30.2	53.3
1 - A	lacustrine	9 - 10'	11.5	3.2	1.1	66.3	29.4	38.0

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations: determined me. per 100 gms. soil	$*Na^{+}$ (% of total)	K^{+} (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
1 - A (cont.)	lacustrine	14 - 15'	12.6	3.8	1.9	77.4	16.9	37.3
	bedrock	19 - 20'	11.7	4.0	2.4	79.3	14.3	37.1
1 - B	till	9 - 10'	14.9	11.5	0.8	77.2	10.5	61.8
	lacustrine	14 - 15'	16.7	21.1	0.9	66.3	11.7	57.0
	lacustrine	19 - 20'	15.8	10.8	1.9	56.9	30.4	32.3
	lacustrine	24 - 25'	14.1	14.3	0.9	73.9	10.9	55.1
	bedrock	29 - 30'	12.0	4.4	1.5	71.4	22.7	40.9
1 - C	till	3 - 4'	14.9	8.4	1.1	65.4	25.1	46.6
	saline till	7 - 8'	20.6	5.6	1.1	82.3	11.0	81.9
	bedrock	9 - 10'	32.6	20.7	0.8	61.8	16.7	79.7
2 - A	till	9 - 10'	14.0	2.9	0.8	82.1	14.2	48.6
	till	14 - 15'	10.9	1.2	1.2	79.8	17.8	41.8
	bedrock	17 - 18'	18.3	3.5	1.2	80.2	15.1	49.1
2 - B	till	8 - 10'	12.4	7.3	0.8	75.3	16.6	35.6
	till	10 - 11'	14.7	5.3	1.1	75.7	17.9	37.4

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations: determined me. per 100 gms. soil	*Na^{+} (% of total)	K^{+} (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
2 - B (cont.)	till	14 - 15'	15.8	5.5	1.3	76.9	16.3	38.0
	bedrock	17 - 19'	16.3	9.2	1.2	75.4	14.2	41.5
2 - C	lacustrine	9 - 10'	10.6	1.9	0.9	79.2	18.0	32.1
	lacustrine	14 - 15'	12.2	2.8	1.2	78.0	18.0	34.5
	till	19 - 20'	12.6	2.4	1.3	84.8	11.5	37.3
	till	24 - 25'	14.1	2.8	1.3	83.9	12.0	39.9
	bedrock	29 - 30'	12.8	4.1	1.2	82.6	12.1	41.2
3 - B	till	9 - 10'	15.6	4.3	0.7	87.8	7.2	58.0
	till	14 - 15'	10.1	2.8	1.3	87.4	8.5	31.6
	till	19 - 20'	16.2	10.8	1.8	80.3	7.1	33.5
	till	24 - 25'	14.6	10.4	1.6	80.2	7.8	36.7
	bedrock	44 - 45'	30.0	15.1	2.0	57.9	25.0	45.6
4 - A	till	9 - 10'	14.9	2.1	0.9	71.7	25.3	44.4
	till	14 - 15'	15.1	1.4	1.0	75.7	21.9	51.1
	till	19 - 20'	14.4	2.5	1.2	76.8	19.5	40.5

* ESP

Table 7. Exchangeable Cation Analysis of Soil and Parent Material Samples

Site No. Profile No.	Horizon	Depth	Total Exchangeable Cations: determined me. per 100 gms. soil	$*Na^{+}$ (% of total)	K^{+} (% of total)	Ca^{++} (% of total)	Mg^{++} (% of total)	sum me. per 100 gms. soil
4 - A (cont.)	sand lens	24 - 25'	12.5	2.0	1.0	69.2	27.8	39.6
	till	29 - 30'	19.2	2.8	1.4	75.5	20.3	43.3
	bedrock	33 - 34'	17.9	2.6	2.1	74.5	20.8	34.1

* ESP

The B horizons of some profiles studied meet the chemical requirements, but do not have the morphological characteristics of Solonetzic B horizons. The B horizons that meet the chemical requirements of Solonetzic B horizons occur in the following profiles:

(1) Profiles 2 to 6 at site 1.

(2) Profiles 2 and 3 at site 2.

(3) Profiles 2 and 3 at site 3.

(4) Profile 2 at site 4.

No notable differences in morphology were detected between the B horizons that met the chemical requirements of solonetzic B horizons, and those that did not.

Little variation was noted in the cation exchange capacities of deep drill samples, in medium-textured lacustrine, till and bedrock materials. Bedrock samples from location C at site 1, and location B at site 3 had high cation exchange capacities, as well as high clay percentages.

V. CONCLUSIONS

Increases in Extent of Soil Salinity

Maps 1 and 2 indicate that the extent of salinity appears to have increased substantially with time. The greatest increase in the extent of salinity is evident in township 17, range 23.

Origin of Salts and Ground Water Movement

Soluble salt analysis of ground water, soil, and parent geologic material samples suggest that bedrock is the main source of the salts. Sodium sulfate appears to be the principal soluble salt accumulated in soil horizons, thus indicating that the major portion of the salts may be transported by regional ground water flow. Higher concentrations of magnesium sulfate than sodium sulfate at site 4 indicate that till may also be a source of the salts. The magnesium sulfate is probably transported by local or intermediate ground water flow. Further evidence that local ground water flow may occur at site 4, is that ground water samples, obtained at this site, contained higher concentrations of magnesium sulfate than sodium sulfate.

Ground water flow patterns cannot be determined from the information obtained from the wells used in this study. Geiger* is of the opinion that the food dye, used to trace ground water movement, was probably carried down slope by perched water tables, resulting from low permeability of the till. Some variations observed in the dye movement, however, may indicate the presence of local flow systems.

Variations in water table levels down slope, at the various sites, are somewhat erratic, and may result from local topographical variations. However, fluctuations in water table levels with the season of the year

---

* personal communication

generally occur. During the period of May to November, 1965, fluctuations in water table levels generally correlated well with precipitation fluctuations in the Vulcan area. Anomalies occurred at site 1 and in well 3 at site 4, where the June water table level did not reflect the large amount of precipitation received during that month. There is no obvious explanation for these anomalies.

Influence of Resalinization upon Genetic Soil Characteristics

The classification of the soils studied is shown in table 8. The soils that are classified as "Orthic Dark Brown", according to the Canadian classification system, and "saline", according to the Handbook 60 classification, have electrical conductivities of >4 and exchangeable sodium percentages of <15. However, these soils do not meet the Canadian definition of saline soils (N.S.S.C.C., 1963).

From the classification, it appears that extensive resalinization of the soils has occurred. However, solonetzic morphological features are not evident in any of the soils studied, possibly because sufficient time has not elapsed for the development of the typical columnar structure (Handbook 60). Lack of development of solonetzic morphology may be attributed to the presence of salts in the sola of soils containing sufficient sodium ion concentrations to initiate the process.

Amelioration of the Salinity Problem

The main causative factor of soil salinity in the problem area is a high water table, and it is likely to continue to carry salts to the surface unless it is lowered by some means. This situation may be corrected by the installation of tile drains at some depth below the water table in order to intercept ground water flow before it reaches the surface. However, if the water table was lowered and the excess

Table 8. Classification of Soils Studied

Site No. Profile No.	Canadian Classification	Handbook 60 Classification
1 - 1	Orthic Dark Brown	Nonsaline - nonalkali
2	Orthic Dark Brown	Nonsaline - nonalkali
3	Saline Dark Brown	Saline
4	Saline Dark Brown	Saline
5	Saline Dark Brown	Saline
6	Saline Humic Gleysol	Saline
2 - 1	Orthic Dark Brown	Nonsaline - nonalkali
2	Orthic Dark Brown	Saline
3	Orthic Dark Brown	Saline
4	Saline Rego Dark Brown	Saline - alkali
3 - 1	Orthic Dark Brown	Nonsaline - nonalkali
2	Saline Dark Brown	Saline
3	Orthic Dark Brown	Saline
4	Saline alluvium	Saline
4 - 1	Saline Dark Brown	Saline
2	Saline Dark Brown	Saline
3	Orthic Dark Brown	Saline
4	Orthic Dark Brown	Nonsaline - nonalkali

soluble salts leached out of the soil sola, sodium-saturated exchange complexes could develop, thus initiating solonetzic soil-forming processes. Furthermore, the economic feasibility of a project of this nature would be questionable.

Possible Future Investigations

The installation of piezometers at different depths and locations, across as well as down the slopes,would provide data, which together with detailed contour maps of the slopes, should be adequate to determine the types of flow systems that exist at each of the sites. This information would be invaluable for planning surface or subsurface drainage systems if reclamation were undertaken.

VI. BIBLIOGRAPHY

Allan, J.A. 1943. Geology, province of Alberta. Research Council of Alberta, Report 34.

Antipov-Karatayev, I.N. and A.A. Kisilova. 1962. Certain types of soil salinization in irrigated zones of Iran. Soviet Soil Sci. 302-310.

Arshad, M.A. 1964. Chemical and mineralogical characteristics of some solonetzic soils in relation to their genesis. Ph.D. thesis, Univ. of Alberta, Edmonton.

Association of Official Agricultural Chemists. 1955. Official methods of analysis. 8th ed. Washington 4, D.C.

Ayers, A.D., A. Vazquez, J. De La Rubia, F. Blasco, and S. Samplon. 1960. Saline and sodic soils of Spain. Soil Sci. 90: 133-138.

Ballantyne, A.K. 1963. Recent accumulation of salts in the soils of southeastern Saskatchewan. Can. J. Soil Sci. 43: 52-58.

Ballantyne, A.K. and J.S. Clayton. 1963. The relationship of water-soluble cations to field separations of Chernozemic and Solonetzic soils. Can. J. Soil Sci. 43: 359-369.

Ballantyne, A.K. and J. S. Clayton. 1964. The relationship of exchange-able cations in the B horizons to the field separations of Solonetzic and Chernozemic soils. Can. J. Soil Sci. 44: 43-49.

Banerjee, S. 1959. Some studies of salt-affected soils of Canning, West Bengal. Plant and Soil 10: 207-219.

Baver, L.D. 1959. Soil physics. 3rd ed. John Wiley and Sons, Inc., New York, N.Y.

Benz, L.D., R.H. Mikelson, F.M. Sandoval, and C.W. Carlson. 1961. Groundwater investigations in a saline area of the Red River Valley, North Dakota. J. Geophys. Res. 66: 2435-2443.

Benz, L.D., F.M. Sandoval, R.H. Mickelson, and E.J. George. 1964. Microrelief influences in a saline area of ancient glacial Lake Aggassiz. II On shallow ground water. Soil Sci. Soc. Amer. Proc. 28: 567-570.

Bettenay, E., A.V. Blackmore, and F.J. Hingston. 1964. Aspects of the hydrologic cycle and related salinity in the Belka Valley, western Australia. Australian J. Soil Res. 2: 187-210.

Campbell, J.D. and J.S. Almadi. 1964. Coal occurrences of the Vulcan-Gleichen area, Alberta. Research Council of Alberta, Preliminary Report 64 - 2.

Cheboratev, I.I. 1955. Metamorphism of natural waters in the crust of weathering. Geochimica Cosmochimica Acta 8: 22-48, 137-170, 198-212.

Cheng, K.L. and R.H. Bray. 1951. Determination of calcium and magnesium in soil and plant material. Soil Sci. 72: 449-558.

Climate of Canada. 1960. Information Services, Dominion Bureau of Statistics, Ottawa, Canada.

Coen, G.M. 1965. Origin of bands in sandy soils of the Stony Plain area. M.Sc. Thesis, Univ. of Alberta, Edmonton.

Darab, K. and I. Szabolcs. 1960. Types of secondary salinization of soils in the irrigated zones of the region of the Great Hungarian Plain. Trans. 7th Intern. Congr. Soil Sci. Madison, Wis. 1: 535-542.

De Sigmond, A.A.J. 1938. The principles of soil science. Thomas Murby and Co., London.

Dodd, J.D., D.A. Rennie, and R.T. Coupland. 1964. The nature and distribution of salts in uncultivated saline soils in Saskatchewan. Can. J. Soil Sci. 44: 165-175.

Doughty, J.L. 1941. The advantages of a soil paste for routine pH determinations. Sci. Agric. 22: 135-138.

Egorov, V.V. 1964. The sodic salinization of the soil in the Soviet Union and some methods of overcoming it. Proc. Symposium on Sodic Soils, Budapest. 99-106.

El Gabaly, M.M. and N.M. Naguib. 1964. Effect of depth and salt concentration of groundwater on salinization of soil. Institute of Land Reclamation, Univ. of Alexandria, U.A.R.

Eremin, G.G. 1953. Salinity of the soils of the Swash region. Vestn. Moskov. Univ. 8, No. 6, Ser. fiz. mat. estestven. Nauk No. 4: 133-144. Abstracted in Soils and Fertilizers 19, Ab. 214.

Farvolden, R. N. 1963. Bedrock channels of southern Alberta. Research Council of Alberta, Bul. 12: 63-75.

Fireman, M. and R.C. Reeve. 1948. Some characteristics of saline and alkali soils in Gem County, Idaho. Soil Sci. Soc. Amer. Proc. 13: 494-498.

Florea, N. and L. Stoica. 1958. Some characteristics of salt accumulation in soils of the northwest Rumanian Plain. Soviet Soil Sci. 830-835.

Geiger, K. W. 1965. Bedrock topography of southwestern Alberta. Research Council of Alberta, Preliminary Report 65-1.

Groenewegen, H. 1961. Composition of the soluble and exchangeable ions of the salty soils of the Mirrool irrigation area (New South Wales). J. Soil Sci. 12: 129-141.

Harris, S.A. 1960. Saline soils in the Kirkuk Plain, northern Iraq. J. Soil Sci. 11: 114-130.

Huber, H. 1961. The influence of the geological conditions on the salinity of the Zam Rud. Salinity problems in the arid zones. Proc. Teheran Symposium, Arid Zone Res. 14: 49-52.

Jackson, E.A., G. Blackburn, and A.R.P. Clarke. 1956. Seasonal changes in soil salinity at Tintinara, south Australia. Australian J. Agr. Res. 7: 20-44.

Janzen, W.K. 1961. Mechanical composition of Solodized Solonetz and Solonetz-like soils of Saskatchewan J. Soil Sci. 12: 101-110.

Janzen, W.K. 1962. Exchangeable cations and mechanical composition of solodic soils of Saskatchewan. J. Soil Sci. 13: 116-123.

Kelley, W.P. 1948. Cation exchange in soils. Reinhold Publ. Corp., New York, N.Y.

Kelley, W.P. 1951. Alkali soils, their formation, properties and reclamation. Reinhold Publ. Corp., New York, N.Y.

Luken, H. 1962. Saline soils under dryland agriculture in southeastern Saskatchewan (Canada) and possibilities for their improvement. Plant and Soil 17: 1-67.

Matzek, B.L. 1955. Movement of soluble salts in development of Chernozems and associated soils. Soil Sci. Soc. Amer. Proc. 19: 225-229.

Meneley, W.A. 1963. Occurrence and movement of groundwater in Alberta. Research Council of Alberta, Bul. 12: 4-12.

Meteorological observations in Canada, monthly record. Dept. of Transport, Meteorological Branch.

Meyboom, P. 1962. Patterns of ground water flow in the prairie profile. Proc. Hydrology Symposium No. 3: Groundwater. 5-20.

Miljkovic, N., A.D. Ayers, and D.L. Eberhard. 1959. Salt-affected soils of Yugoslavia. Soil Sci. 88: 51-55.

Molina, J.S. and C. Sauberan. 1964. Reclamation of sodic soils by biological methods. Proc. Symposium on Sodic Soils, Budapest. 411-414.

Molodtsov, V.V. 1961. Nitrate solonchaks of the Murgab Oasis. Soviet Soil Sci. 659-663.

Moss, E.H. 1955. The vegetation of Alberta. Boton. Rev. 21: 493-567.

Muratova, V.S. 1958. Salt accumulation processes in the soils and ground water of the Mils'k Plain, Kura-Araks Lowland. Soviet Soil Sci. 613-622.

National Soil Survey Committee of Canada. 1963. Report on the fifth meeting held at Winnipeg, Manitoba.

National Soil Survey Committee of Canada. 1965. Minutes of the sixth meeting held at the Univ. of Laval, Quebec City, Quebec.

Pekatoros, L.G. 1960. Process of salt accumulation in soils of the southern Bug flood plain. Soviet Soil Sci. 821-827.

Pratt, L.E. and J.H. Ellis. 1954. The nature and distribution of saline soils in Manitoba. Can. J. Agric. Sci. 34: 364-373.

Qayyum, M.A. and W.D. Kemper. 1962. Salt concentration gradients in soils and their effects on moisture movement and evaporation. Soil Sci. 93: 333-342.

Ravikovitch, R., H. Koyumdjisky, and Y. Dan. 1960. Soils of western and central valley of Yizreel. Agric. Res. Station, Israel, Bul. 64: 41 + XI. Abstracted in Soils and Fertilizers 24, Ab. 839.

Raychaudhuri, S.P. and N.R. Datta Biswas. 1954. Saline and alkali soils of Asia with particular reference to India. 5th Intern. Congr. Soil Sci. 1: 191-207.

Raychaudhuri, S.P. 1964. Classification and management of saline and alkali soils of India. Proc. Symposium on Sodic Soils, Budapest. 83-89.

Remson, I., J.R. Randolph, and H.C. Barksdale. 1960. The zone of aeration and ground water recharge in sandy sediments at Seabrook, New Jersey. Soil Sci. 89: 145-156.

Rennie, P.J. 1957. Effect of the afforestation of catchment areas upon water yield. Nature Lond. 180: 663-664. Abstracted in Soils and Fertilizers 20, Ab. 2028.

Richards, L.A. 1950. Chemical and physical characteristics of saline and alkali soils of western United States. Trans. 4th Intern. Congr. Soil Sci., Amsterdam. 1: 378-383.

Russell, L.S. and R.W. Landes. 1940. Geology of the southern Alberta plains. Geological survey of Canada, Memoir 221.

Sandoval, F.M. and L. Shoesmith. 1961. Genetic soil relationships in a saline glacio-lacustrine area. Soil Sci. Soc. Amer. Proc. 25: 316-320.

Sandoval, F.M., L.C. Benz, and R.H. Mickelson. 1964. Chemical and physical properties of soils in a wet saline area in eastern North Dakota. Soil Sci. Soc. Amer. Proc. 28: 195-199.

Sandoval, F.M., L.C. Benz, E.J. George, and R.H. Mickelson. 1964. Micro-relief influences on a saline area of glacial lake Agassiz: I On salinity and tree growth. Soil Sci. Soc. Amer. Proc. 28: 276-280.

Schoonover, W.R., M.M. El Gabaly, and M.N. Hassan. 1957. A study of some Egyptian saline and alkali soils. Hilgardia 26: 565-596.

Siline-Bektchourine, A.I. 1961. Conditions of formation of saline waters in arid zones. Arid Zone Res. 14: 43-47.

Sokolovskiy, S.P. 1960. Characterization of the present saline soils in the Terek river delta. Soviet Soil Sci. 516-524.

Sukhachev, S.I. 1958. Salinization of soils at the periphery of the Sokh alluvial fan. Soviet Soil Sci. 70-76.

Todd, D.K. 1959. Ground water hydrology. John Wiley and Sons Inc., New York, London.

Tolman, C.F. 1937. Ground water. McGraw-Hill Book Co., Inc. New York and London.

Toogood, J.A. and T. W. Peters. 1953. Comparison of mechanical analysis of soils. Can. J. Agr. Sci. 33: 159-171.

Toth, J. 1962. A theory of groundwater motion in small drainage basins in central Alberta, Canada. J. Geophys. Res. 67: 4375-4387.

Toth, J. 1963. A theoretical analysis of groundwater flow in small drainage basins. J. Geophys. Res. 68: 4795-4812.

Truss, P.S. 1959. Salt regime of the soils of central Baraba with reference to their drainage. Soviet Soil Sci. 681-694.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Agr. Handb. 60. U.S. Gov't. Printing Office, Washington, D.C.

Vilenskii, D.G. 1957. Soil Science. 3rd ed. State Teachers Col. Publ. House. Ministry of Culture, Russian Soc. Fed. Soviet Rep., Moscow.

Vodenicharov, I.N. 1959. Solonetzic soil of the Frakia depression in Bulgaria. Soviet Soil Sci. 1090-1099.

Wells, R.E. A parent material study of two Solonetzic soil sequences in southern Alberta. M.Sc. Thesis, Univ. of Alberta, Edmonton.

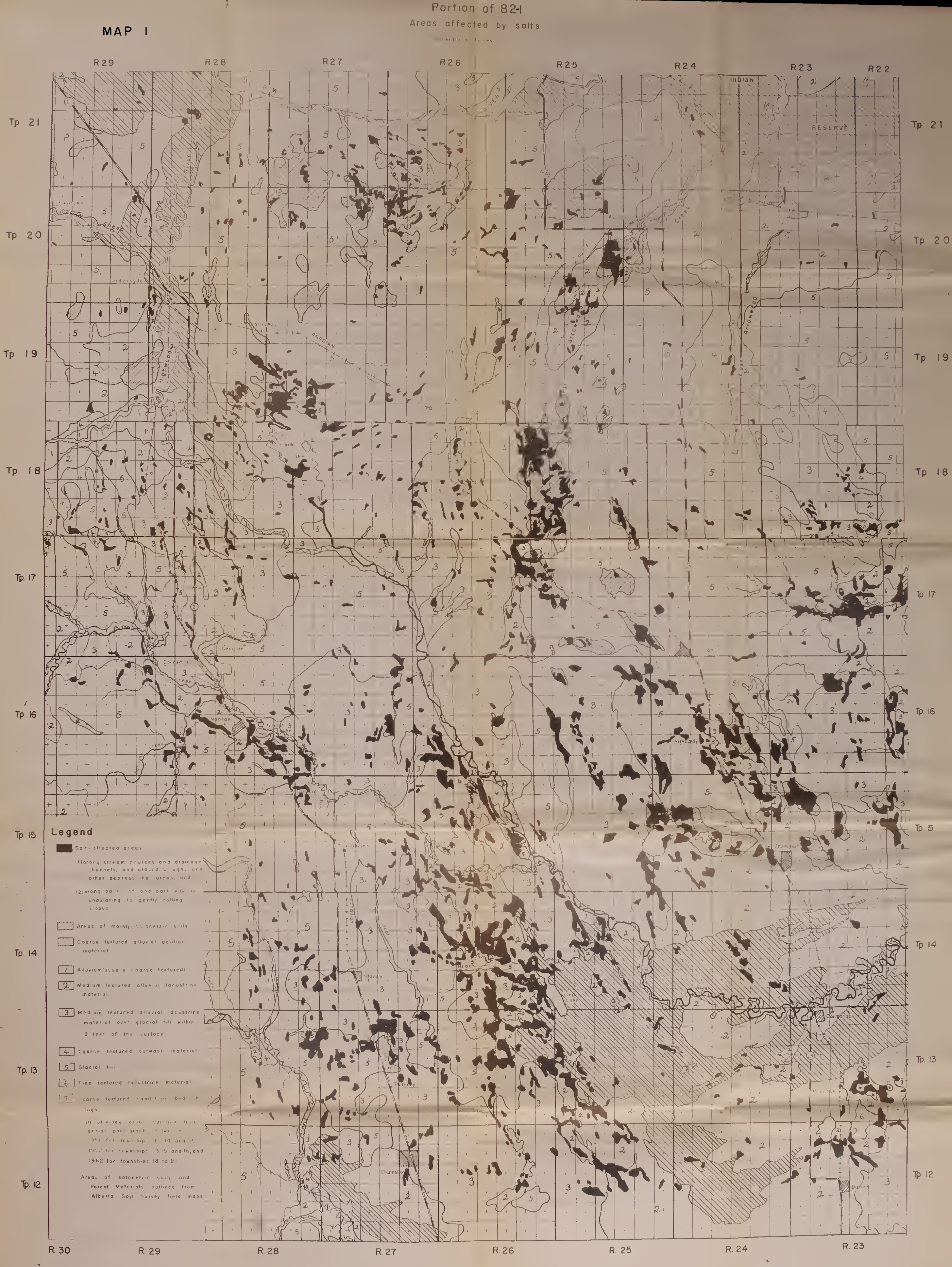
Wilde, S.A., E.C. Steinbrenner, R.S. Pierce, R.C. Dosen, and D.T. Pronin. 1953. Influence of forest cover on the state of the ground water table. Soil Sci. Soc. Amer. Proc. 17: 65-67.

Williams, M.Y. and W.S. Dyer. 1930. Geology of southern Alberta and southeastern Saskatchewan. Geological Survey of Canada, Memoir 163.

Wyatt, F.A. and J.D. Newton. 1925. Soil Survey of Macleod sheet. Dept. of Extension, Univ. of Alberta, Bul. 11.

Wyatt, F.A., J.D. Newton, W.E. Bowser, and Wm. Odynsky. 1942. Revised by T.W. Peters and W.E. Bowser. 1960. Soil Survey of Blackfoot and Calgary sheets. Dept. of Extension, Univ. of Alberta, Bul. SS-2.

Yegorov, V.V. 1961. Sodium carbonate salinization of soils in Sinkiang. Soviet Soil Sci. 479-487.



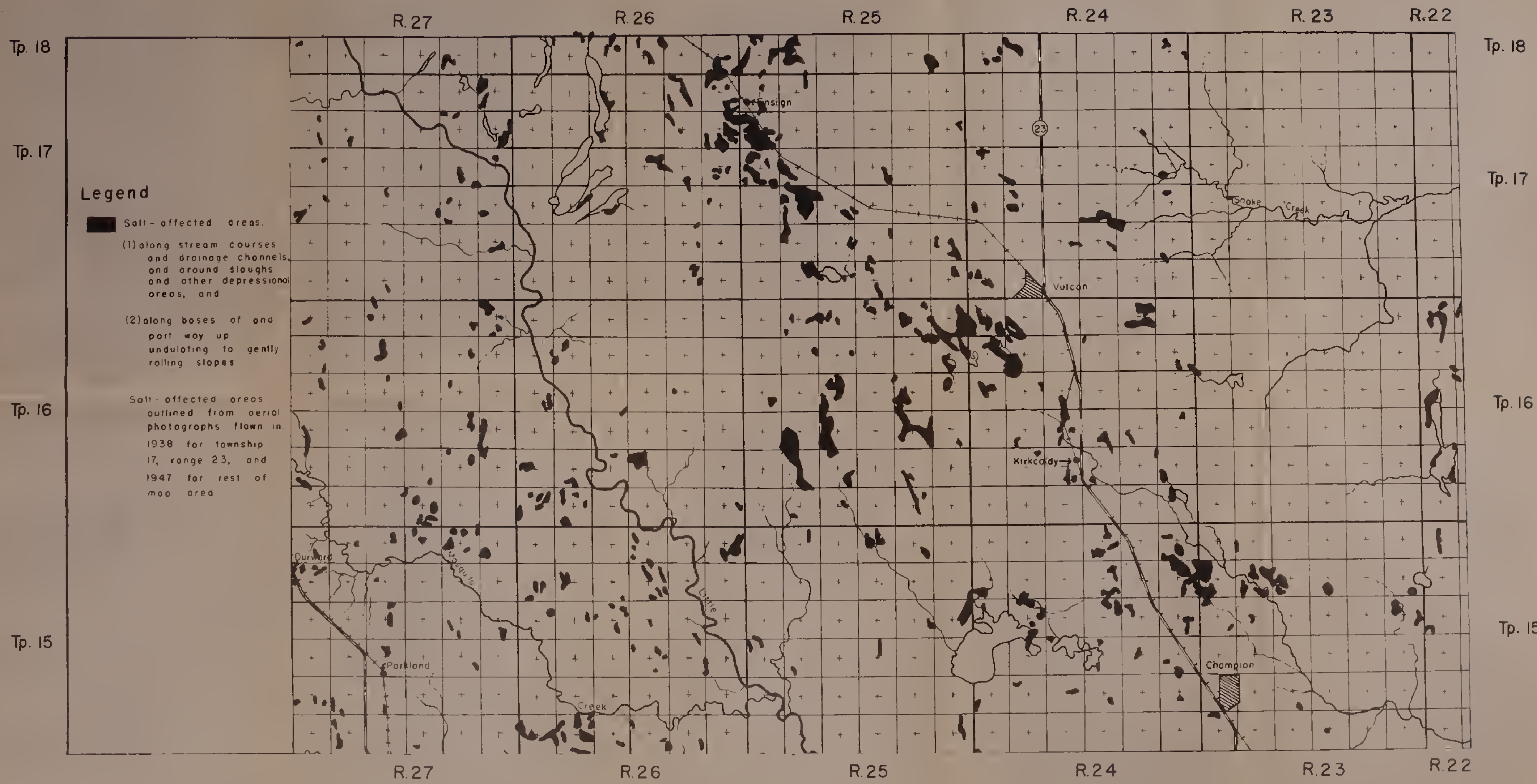
MAP I
Portion of 82-I
Areas affected by salts
R29
R28
R27
R26
R25
R24
R23
R22
Tp 21
Tp 20
Tp 19
Tp 18
Tp 17
Tp 16
Tp 15
Tp 14
Tp 13
Tp 12
R. 30
R. 29
R. 28
R. 27
R. 26
R. 25
R. 24
R. 23
INDIAN
RESERVE
Nanton
Champion
Carmangay
Claresholm
Legend
Salt-affected areas
Areas of mainly solonetzic soils
Coarse textured alluvial aeolian material
1 Alluvium(usually coarse textured)
2 Medium textured alluvial lacustrine material
3 Medium textured alluvial lacustrine material over glacial till within 3 feet of the surface
4 Coarse textured outwash material
5 Glacial till
6 Fine textured lacustrine material
1962 for townships 18 to 21
Areas of solonetzic soils, and Parent Materials outlined from Alberta Soil Survey field maps

MAP 2

Portion of 82-I

Areas affected by salts

Scale 1 inch = 2 miles



MAP 3

SURFACE CONTOURS of PORTION of 82-1

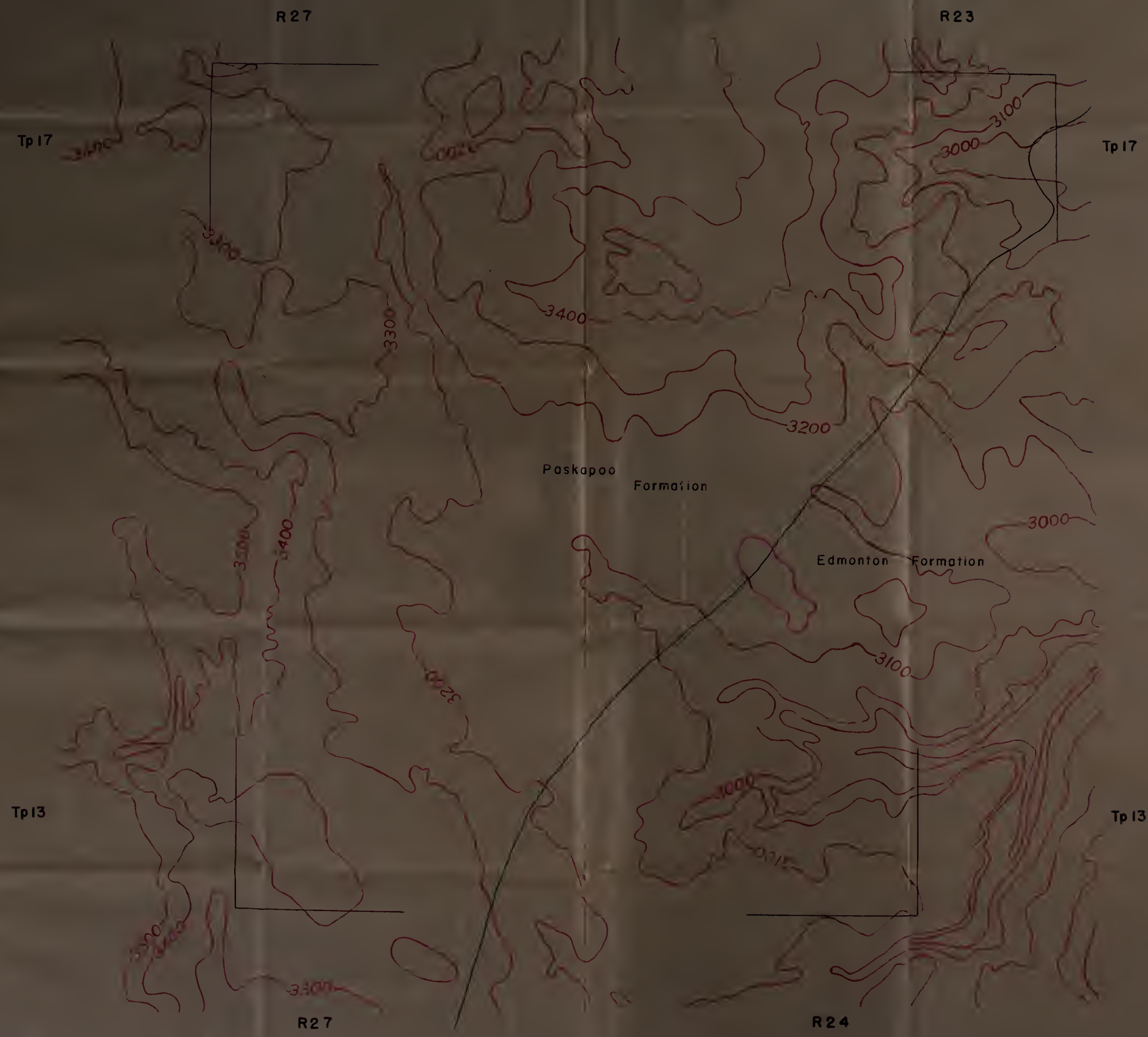
Scale: 1 inch= 2 miles

Contour interval: 100 feet

MAP 4

CONTOUR MAP of BEDROCK SURFACE of PORTION of 82-1

Scale: 1 inch = 2 miles



Contour interval: 100 feet